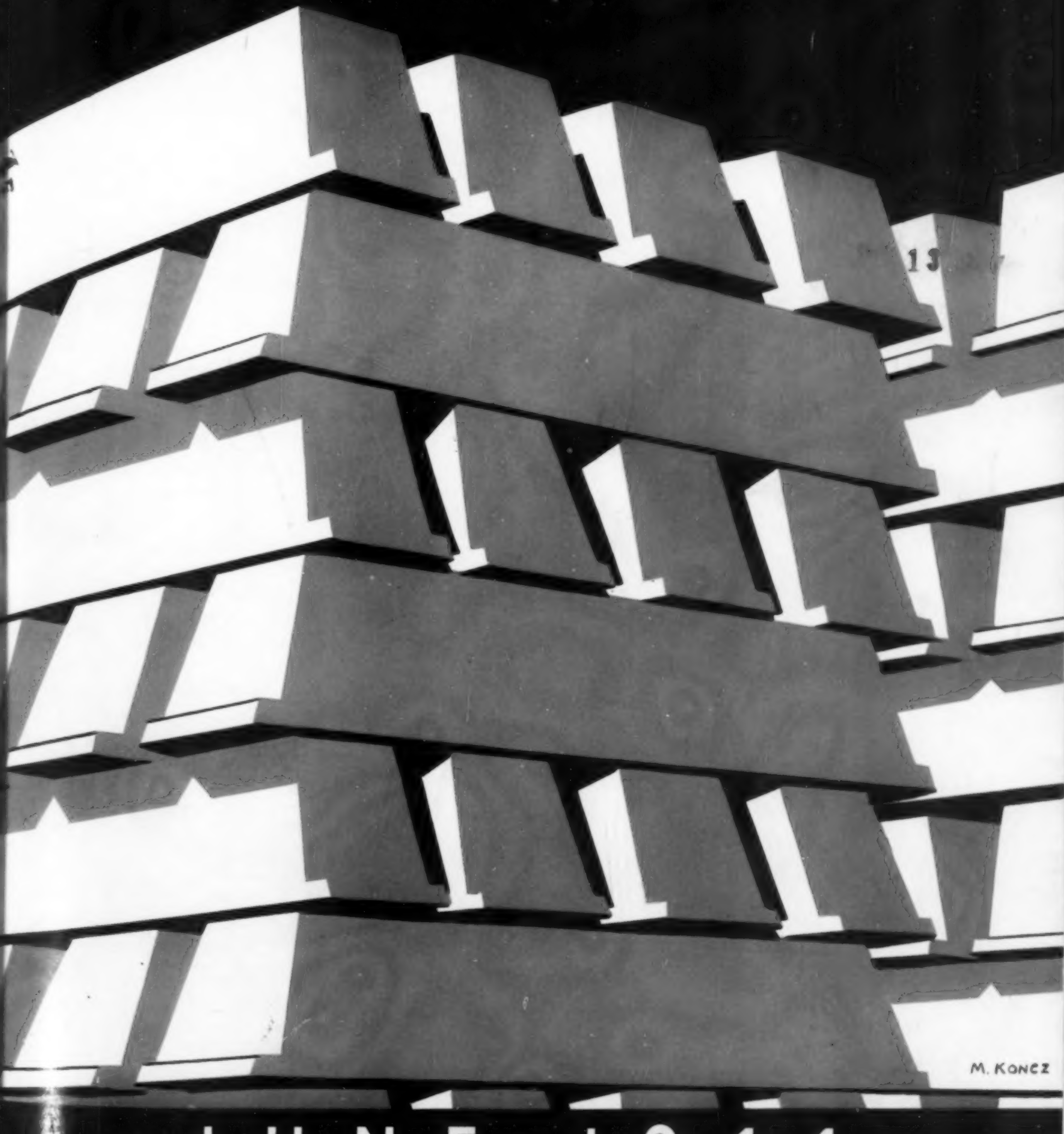
METAL PROGRESS



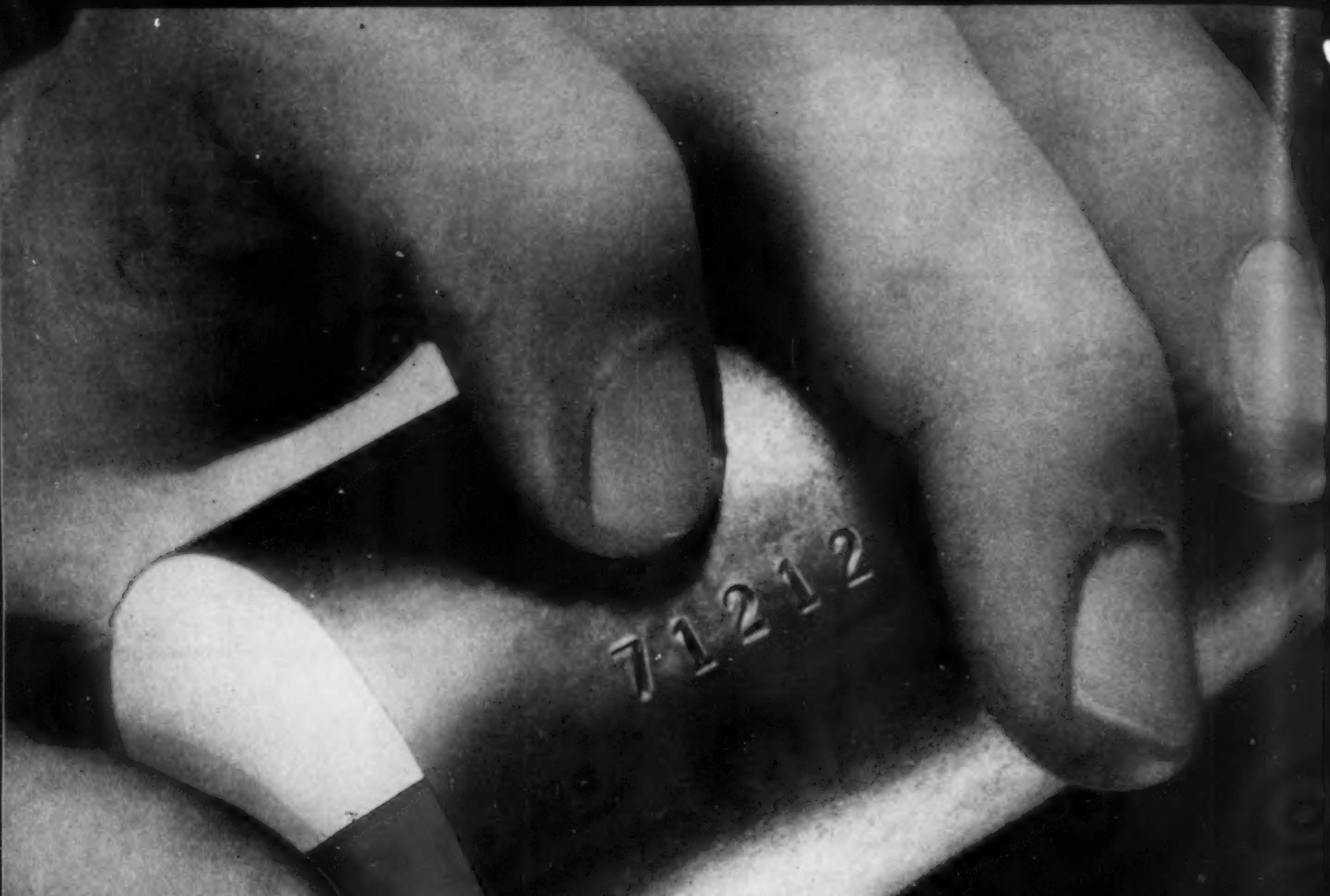
JUNE 1944

METAL PROGRESS

Vol. 45 ***June, 1944*** ***No. 6***

Table of Contents

Index to Volume 45 will be found following the advertising insert, facing page 1110-D


71212

Portions of a paper read last year before the Ontario Chapter ⓐ, which described the changes in peace-time operations necessary to produce gun tubes, armor plate and other heavy ordnance materiel at Dominion Foundries & Steel, Ltd.

Manufacture of Homogeneous Armor, Both Cast and Rolled

TRANSITION in our shops from the production of peaceful equipment, such as railroad castings, forged axles, sheared and universal plate — all in carbon steel — to semi-finished gun barrels and jackets, hardened armor and bullet-proof plate, tank turrets and similar war equipment has involved many difficulties and has required the shopmen and management to master many new skills. Of this, perhaps the items of most general interest relate to the manufacture of armor, and we can start with the most unusual type — a product of the present emergency — cast armor.

"Scheduling" of castings, such as the M-3 turrets, is a most important preliminary to steady production. Practically all steel for castings is produced in one 1½-ton and three 10-ton electric furnaces. Inasmuch as the most of our foundry output is 0.20% carbon steel, the carbon steel castings can be molded *ad lib,* since there will be little difficulty in getting liquid steel of correct analysis for them. High carbon or alloy steel castings, however, must be molded in sufficient quantity to receive a special heat from any one of our furnaces.

Next the most important factor in early and satisfactory production is the proper location of heads and feeders. This is carefully gone over by our foundrymen, even though we are furnished the patterns. Correct gating can, in a good many instances, be very difficult, yet is essential for sound castings. All elements of good sand control, molding and core room practice are also factors in a low percentage of rejects. Chills are frequently used to counteract the variable shrinkage and cracking due to thin versus thick sections; they are proportional in mass to the wall thickness of the casting alongside. Ample heads or risers, placed in correct positions, are the principal means of avoiding internal cavities. One thing that is frequently forgotten is that the connection between casting and shrink head must be as large as possible so it will not freeze before the casting has solidified and check the flow of metal downward. Heads are sometimes covered with "pipe eliminator", a heat producing compound that keeps the risers molten until the last.

Sprue placement is part of the good foundryman's art. Certain principles govern:

The sprue should not be placed where it will produce a shrinkage cavity.

The sprue should be located far enough from the edge of the mold to insure a thickness of sand having ample strength to prevent the high metal pressure in the sprue from breaking through into the mold; this precaution is especially important in deep molds.

The metal entering the mold

1. Must not spatter on the sides of the mold.

By D. O. Davis
Engineer in Charge of Maintenance and Improvement
Dominion Foundries & Steel, Ltd.
Hamilton, Ontario

2. Must not have too far to run after entering.

3. Must not be permitted to form eddies.

4. Should not come in contact with sharp corners.

5. Should be permitted to fill the mold quickly by having the gates and sprues sufficiently large.

Such a large amount of metal is required to feed a complicated alloy casting that the yield is only about 50% of the melt — that is, 50% becomes "foundry returns".

A casting, arriving in the cleaning room from the foundry floor, has little resemblance to the desired finished product. Heads, gates, adhering molding sand and chills are excess materials which must be removed. Metal fins, chills, bulky sand patches and cores are removed by chippers, using air hammers and sand chisels. Next the castings are thoroughly cleaned; large ones by shot blasts — shot forced through a nozzle by compressed air — smaller castings by "Wheelabrator Tumblasting" which leaves a very satisfactory finish.

Heads and gates are removed by various methods, such as gas cutting, cold sawing, sledge hammer and grinder cut-off. Gas cutting is the most common, while small castings now have heads and gates removed on a grinder cut-off machine. Some high carbon and alloy castings are heated to 500° F. or more before they are gas cut so as to eliminate cracking on the cut edges. Such work must be done as quickly as possible after a heavy piece has been drawn from the furnace to avoid large temperature differences between interior and outside. The part remaining after cutting is usually smoothed up by grinders.

Heat Treatment of Alloy Castings

Depending on required properties and analysis, steel castings are given one of several heat treatments such as *(a)* annealing, *(b)* normalizing and annealing, *(c)* normalizing, quenching and drawing.

Annealing — The purpose of annealing steel castings is:

1. To soften the steel so it will meet certain physical requirements or make it easier to machine.

2. To remove internal stresses and strains.

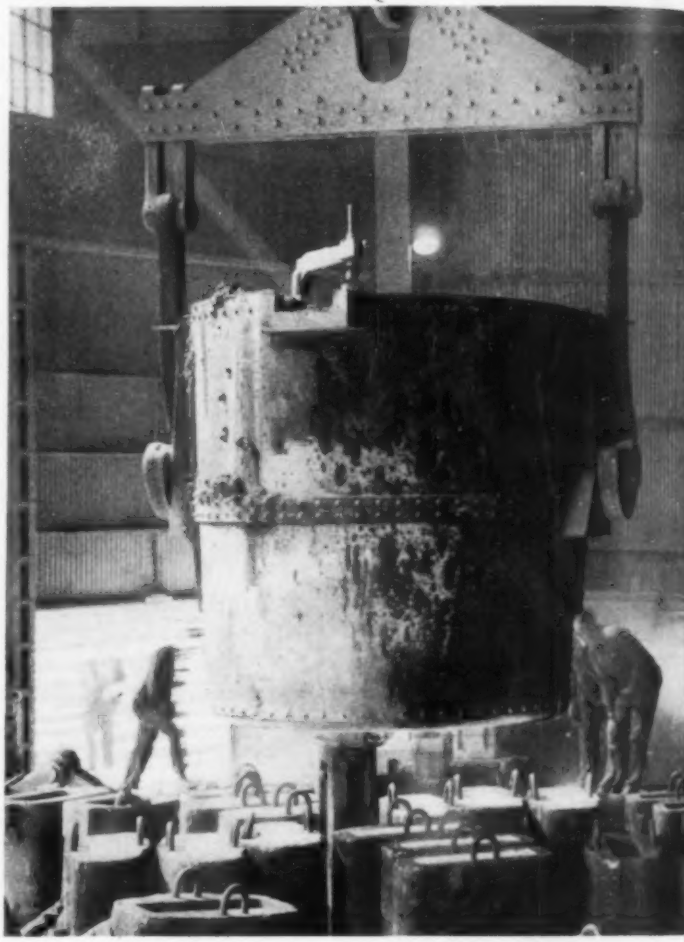


Fig. 1 — Teeming 50 Tons of Electric Steel Into 12 Bottom-Cast Ingot Molds With Suspended Hot Tops

3. To alter ductility, toughness, electrical magnetic or other physical properties.

4. To refine coarse grain so as to secure more desirable combination of strength, elasticity and ductility.

Castings are placed in the annealing furnace in such a manner as to ensure an even distribution of heat to every part, and the temperature then raised about 100° above the upper limit of the critical temperature — which, for ordinary carbon steel, is about 1650° F. In passing through the critical range, the cast, coarse-crystalline structure of the metal is converted into a new much more finely-grained structure. Carbon and the other soluble alloying elements also have chance to distribute themselves much more uniformly throughout the metal. (Sulphur, dirt, slag and trapped oxide particles are, however, not affected in size, location or influence by annealing treatments; naturally they are kept at the very minimum by sound melting and pouring practices.) Length of time to reach temperature increases with the size of the casting; it is

lways well to have a thermocouple placed in hat portion of the furnace load which is likely o reach temperature last.

Once the annealing temperature is completely eached, the castings should remain there about hr. for each inch of thickness of their largest ection. During this time, the firing should be uch that the outer and most exposed portions f the load do not become overheated.

In order to have easy machinability, the steel astings are left in the furnace to be cooled until temperature of 800° F. or less is reached. They may then be withdrawn from the furnace to inish cooling to ordinary air temperature.

Normalizing — The normalizing process is he same as annealing with the exception that, fter being held at proper temperature a specified ength of time, the castings are withdrawn from he furnace and air cooled instead of furnace ooled. The so-called "double treatment" is a ormalizing followed by a ull annealing. Normalizing is sometimes called a "still air quench", and by irtue of the fact that the teel passes down through he critical range at a much aster rate than when cooling in the furnace after annealing, the transformation structure is much finer as viewed under he microscope, and the hardness and strength of the casting are greater. However it is not quite so ductile nor machinable.

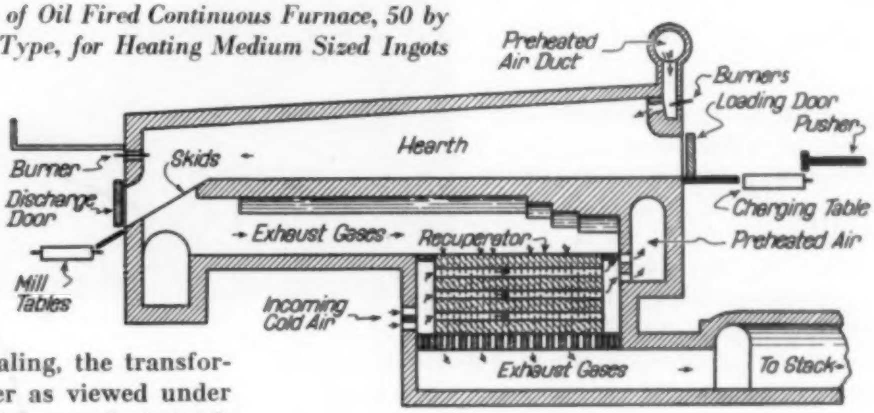
Quenching — When exceptional physical properties are needed in steel castings, heating and quenching of the castings give the desired results. The order of increasing intensity (faster cooling rate) is: *(a)* Still air, *(b)* air blown on the work from a fan, *(c)* oil bath, *(d)* water sprays, *(e)* salt brine solutions in tank, *(f)* refrigerated brine sprays. Rapidly quenched steel castings are like any other quenched steel — are hard in relation to their carbon and alloy content and the speed with which they are cooled. (It is very difficult to get a *fast* quench in a *heavy* steel section.) Quenched steel is drawn back to appropriate temperatures to relieve the internal quenching stresses, and restore a degree of shock resistance and toughness without materially reducing the hardness. The problems of quenching and drawing steel castings are quite similar to the problems of heat treating heavy forgings, and are too complex to discuss at any length here.

Furnaces are usually the car-bottom type in which the loading and unloading is done under a craneway in front of the furnace. Some heavy castings are annealed in a continuous furnace, pushed through on skids by a mechanical pusher. A heavy grade of oil, known as "Bunker C" is used by us for fuel.

Straightening may be avoided, in part, by careful loading and support during annealing. Unavoidable distortion may be corrected in hydraulic presses. This can be done at room temperature on low carbon steel castings; alloy castings must be preheated before straightening.

Very large castings, which cannot be mechanically pressed because of their size, must be made level during the annealing or heat treating operation. This is done by bedding the casting on level surfaces in the furnace. During heating the casting surfaces will drop to the required positions made by the bedding.

Fig. 2 — Longitudinal Section of Oil Fired Continuous Furnace, 50 by 13½ Ft. Hearth, Recuperator Type, for Heating Medium Sized Ingots

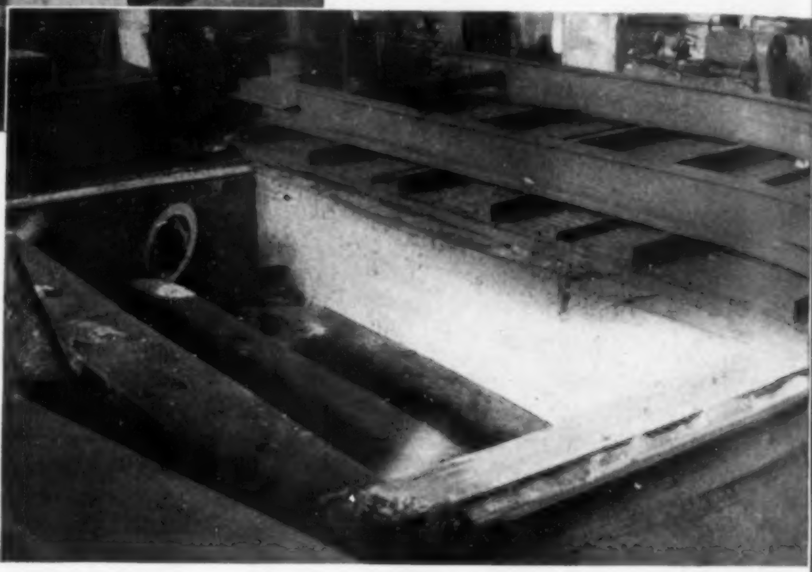


Rolled Armor and Bullet-Proof Plate

Since Dominion Foundries pioneered the production of armor plate in Canada, practically all the experimental work on that product in the Dominion has been done at our plant. The present analysis, melting and rolling methods, and correct heat treatment have been found mainly by this experimental work. It has been found that two grades of alloy steel will satisfy the requirements, and these experiments have been responsible for a change from the predominantly nickel type of steel in guns to a steel whose principal alloying element is chromium.

Melting — Armor plate is made in a 50-ton, top charged, electric furnace which has a 10,000 kva. transformer with a voltage range of 262 to 95 volts. Incoming voltage is 13,800 and the system operates on 25 cycles. Average amperes are 13,770 with a peak of 45,000. The diameter of the furnace shell is 17 ft. and the electrodes are 18 in. diameter.

Fig. 3—Asbestos Coated and Hooded Workmen Adjust Slings In Order to Transfer Annealed Plates While Still Hot to Holding Pits (Fig. 4) to Await Torch Cutting to Shape



The furnace charges are made in the following sequence: Limestone; return scrap, then some turnings; balance of miscellaneous scrap; ore; and finally the alloy additions.

From practice, it has been found desirable to melt fast, to use the high tap as quickly as possible, and keep on this tap until the charge is melted completely. No additions, except scrap recharges, are to be made during the melt-down.

Time for a normal heat is 6 to 8 hr. The steel is tapped at a temperature of 2980 to 3020° F., as measured by optical pyrometer.

Ingot Practice — Molds are warm, free from fire cracks, properly washed, accurately centered over runner openings, plugs dry and carefully set free of rust, and all runners thoroughly clean. Figure 1 shows a group of 12 molds being bottom-cast simultaneously. *Hot, clean* ladles are essential; 3-in. nozzles are used on all armor plate heats. All hot tops are warm and *dry* before they are set in the molds. Desired pouring temperature is between 2880 and 2920° F. Ingots vary in cross section from 9 x 24 in. to 20 x 42 in.

Ingots and molds are allowed to stand undisturbed for 1½ hr. after being poured. Hot tops are then broken off and the ingots of the first group stripped and loaded onto the transfer car before proceeding with the stripping of the second and third groups. Every effort is made to have each ingot as free from hot top refractory as possible before sending it to the soaking pits.

Ingots are delivered from the melt shop over an inter-department broad gage track system to an open yard which serves as a mold and ingot storage (and also as a torch cutting department for slabs and heavy plates). One practice which is very important is to see that each car of ingots is covered completely with a steel hood during transport.

Ingots are delivered to either the soaking pits or to one of two continuous furnaces for heating before rolling. The heavier ingots are charged into the pits and the lighter ones go through the furnaces. Fuel is a heavy grade of "Bunker C" fuel oil, heated to 180° F. by steam before being pumped under a pressure of 60 psi. to the burners. Air is supplied to the burner at 800° F. and 5 in. of water pressure. The atomizer is located in the center of the burner and the oil enters through a center pipe — the steam for atomization around it.

Soaking pits are of most modern type. The continuous furnaces, shown in diagrammatic cross section in Fig. 2, are of unusual design. One has a hearth 30 ft. long, the other 50 ft. Both are 13 ft. 6 in. wide inside and are top fired from the charging end by five oil burners, supplemented by one at the discharge end.

The combustion gases flow toward the discharge end, and then down and back under the hearth to a refractory tile recuperator. Preheated air, furnished by this recuperator, is injected into the furnace above the ingots by the oil burners at the charging end.

Ingots are end charged in two rows by a mechanical type pusher and are end discharged onto the mill approach table.

Armor plate ingots are put into soaking pits as quickly as possible after arrival. Temperature of the pit is adjusted to the temperature of the ingot by proportion to the time between finish of pouring and arrival, thus:

Age of Ingot	Maximum Temperature of Pit at Charge
Under 3 hr.	1700° F.
4 hr.	1560
5 hr.	1420
6 hr.	1300
7 hr.	1160
8 hr.	1030
Over 8 hr.	Under 1000° F.

If ingots are allowed to go cold they are charged to the pits at a temperature not exceeding 800° F. The ingots are first allowed to soak in the pits for 30 min. before the fuel is turned on, then the pits are brought up to a rolling temperature (2250 to 2300° F.) at a rate not in excess of 150° F. per hr. The ingots are in the pits a minimum of 4 hr.

Rolling — The rolling mill equipment already installed for universal and sheared plate, and ordinary rolling mill practices, have proved quite adequate for the production of ballistic plate.

In the universal mill all rolling is completed before the temperature falls below 1360° F. The hot mill takes every precaution to insure that all scale is removed in the early stages of rolling, and that a good clean surface is produced.

Universal plate is rolled on the 2-high mill in the same manner as hot strip breakdowns, the range of sizes being from ¼ x 8 in. to 1 x 36 in. Two examples of ingot sizes used for various finished plate are:

Plate ¼ to ⅜ in., 8 to 12 in. wide, is rolled from a 7 x 14-in. ingot.

Plate ½ to 1 in., 14 to 20 in. wide, is rolled from a 14 x 22-in. ingot.

The heaviest armor plate, 60 mm., is rolled from a 15 x 42-in. ingot in 21 passes.

Sheared plate is roughed down on a 2-high mill and finished on a 4-high mill. For example ¾ x 72-in. plate is roughed to 2⅜ in. from a 20 x 40-in. ingot; ⅜ x 72-in. plate is roughed to 1½ in. from a 12 x 42 x 40-in. ingot; ¼ x 72-in. plate in roughed to $1\frac{3}{16}$ in. from a 12 x 37-in. ingot. All these are finished on the 4-high mill.

All plate passes through a 110-in. leveller en route to end and side shears. Minimum top discard is 20% and bottom discard is 3%.

Bullet-Proof Plate, in distinction from armor plate, varies from 3 to 12 mm. in thickness and 22 to 60 in. in width. Ingots for these sizes vary in cross section from 8½ x 22 in. to 15 x 42 in.

In rolling 3-mm. plate, the ingot is first slabbed to 3 x 33 x 42 in., reheated and rerolled 7 passes on the 2-high mill, reducing it from 3 in. to ½ in. The ½-in. breakdown is delivered to the 4-high mill where, in 5 passes, it is reduced to 0.130 in.

Heat Treatment of Medium Armor

Reverting again to heavy gage armor, 1 in. thick or thicker, plates are cropped as follows:

(a) Top discard by cutting 6 in. below hot top junction.

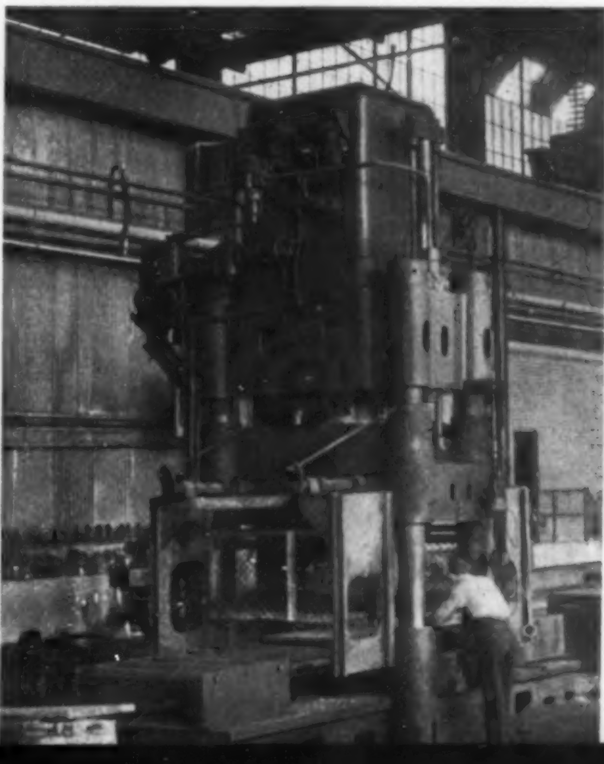
(b) Bottom discard, at least 3% of length.

All plate is inspected on both surfaces before heat treating. Inspectors report the total length of good plate in each ingot, and the location and type of all surface defects. Reports show the surface quality of each heat with ingots arranged according to group marking.

Plates are annealed at 1650° F., to relieve rolling strains and to soften the steel, in 8 x 24-ft., car-type, overfired, 3-zone control, gas furnaces. The cycle takes 24 hr. The average charge is 50 tons of plate, piled on the car in two piles placed lengthwise. Rails and 2½-in. square billets are used as separators. On the completion of the annealing cycle, the car is pulled and the plates allowed to cool to about 800 or 1000° F.

Because it is necessary to have temperature in the plates during torch cutting, they are next placed in holding pits (Fig. 4) which are maintained at roughly 900° F. Planographs, travo-

Fig. 5 — Oil Hydraulic Press Straightening Medium Armor by Pinching Between Three Vee Blocks



graphs, and radiagraphs are used to cut plates to templates which vary in size from 32 in. x 15 ft. to 5 x 5 in. Plates, after being torch cut, are piled with separators between them on the 8 x 24-ft. cars at the overfired hardening furnaces. These furnaces are brought up to 1650° F. and then held at that temperature for 6 hr.

At the end of the required time, the furnace is opened, the car bottom pulled out, and plates taken one at a time by a special "C-hook" and water quenched. The tank is 10 x 30 ft. in area and 10 ft. deep; circulation of cool water is adequate. After six plates have been quenched, the car is pushed back in the furnace for about 20 min. so that the remaining plates may pick up temperature. After the plates are quenched down to about 500° F., they are re-piled with separators on a similar car bottom at a tempering furnace, gas fired, with recirculating atmosphere. Drawing cycle is 1150° F. for 5 hr., whereupon the plates are transferred to another pit (Fig. 4) at 900° to retain heat for press flattening.

Press straightening is a relatively simple operation, although it requires a lot of skill to adjust the "pinch" to the correct amount, and a lot of strength to manhandle the long plates. Our 750-ton oil hydraulic press used for this operation is shown in Fig. 5. Roller tables are built at either side for aiding the workmen. The anvil has a parallel pair of husky inverted Vees set some 8 in. apart. The upper platen has a single blunt nosed vee set midway between the lower ones. The straightening operation therefore consists of a series of pinches which cause short kinks in the plate in a direction opposite to the curvature existing in it. Finally, plates must have no variation of more than $\frac{3}{32}$ in. from a straight line or flat plane in a length of 16 ft.

Finally the plates are spread out on the inspection tables, the hardness taken on a power driven Brinell tester, and a test coupon cut off and broken.

Sequence of operations for the heavier plate is, therefore

1. Cut ends and inspect.
2. Anneal.
3. Place in holding pit.
4. Cut to template.
5. Harden.
6. Quench.
7. Draw.
8. Place in holding pit.
9. Press for flatness.
10. Inspect and ship.

Routine for the class we call "light armor plate", ranging from 12 to 30 mm. (½ to $1\frac{3}{16}$ in.) inclusive, is somewhat different, up to item 5. Much of the cutting is done on shears. The lighter gages are flattened on roller levellers while still warm after the anneal. Heat treatment is done in the continuous Drever furnace, as outlined below. The above remarks also apply to the "bullet-proof steel".

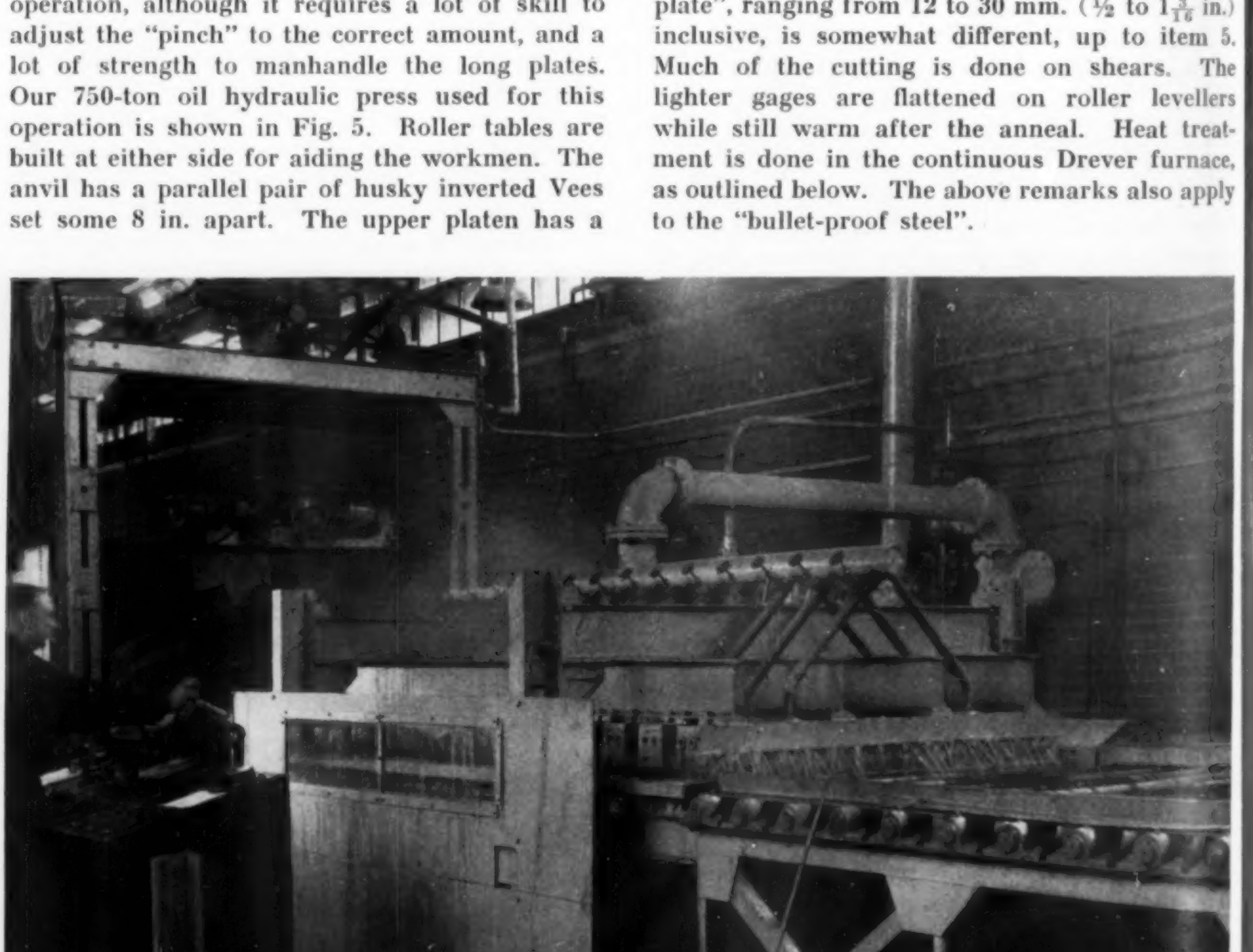


Fig. 6 — Quenching Fixture for Hardening Plate. A duplicate is used for chilling plate after the draw

Continuous Heat Treatment of Light Armor and Bullet-Proof Steel

Continuous treatment is done in the "Drever" furnace line which consists primarily of an approach table leading into the hardening furnace at the start of the operation. This is 40 ft. long, oil fired with burners enclosed in combustion chambers under the roller hearth. Temperature is automatically controlled in four zones, and plates are discharged at 1650° F.

They go immediately forward to the quenching press shown in more detail in Fig. 6. It consists of two sets of stiff rollers, one fixed in the plane of the transfer table and the other set attached to a grillage of I-beams, which in turn is connected through masts at the four corners to the plunger of a 150-ton hydraulic cylinder set below the floor. When a hot plate is run out of the furnace (all movements being controlled by the operator at the switchboard alongside) the upper rolls clamp down, holding the moving plate flat while a multitude of water sprays hit it top and bottom.*

The quenched plate, cooled to 200 or 300° F., then enters the 40-ft. tempering furnace by power driven roller tables. It is under two-zone control, each zone having independently re-circulated atmosphere. Out of the draw furnace the plate is quenched dead cold in a press, a duplicate of the one illustrated, Brinelled in a motorized hardness tester, and delivered to bending brakes for final straightening.

Drawing temperatures vary from 975 to 1200° F. depending on the gage of the plate. Times also vary. Typical schedules are:

For 1-in. plates the furnaces are set at 2-hr. cycles; the plates are quenched to about 100°, and the draw furnaces run at the higher temperature of 1200°.

For 1½-in. plates the furnaces are set at 3 hr., the plates are quenched to about 200 to 300°, and the draw furnace is run at 1200°. After the plates are straightened, thicknesses up to 17 mm. are ballistically tested, then shipped.

*Editor's Note — Cold straightening of heat treated homogeneous armor plate was, during the early months of the war, a most time consuming operation, farmed out widely to sub-contractors in the sheet and plate industry who had bending brakes of sufficient capacity. Costs ran up to 10¢ per lb. Quenching fixtures of numerous designs quickly appeared, and have avoided most of this work. Typical are the "waffle iron" dies designed by Carl G. Strandlund at Chicago Vitreous Enamel Product Co., and installed in a 2500-ton hydraulic press. Some 7200 holes in the dies spray pressure water in against the plate. This fixture alone avoided the use of 25 cold straightening presses.

Openhearth Metallurgists Discuss Production Problems

Reported by Frank G. Norris
Assistant Metallurgical Engineer
Wheeling Steel Corp.

YOUR REPORTER accepted the assignment of recording for *Metal Progress* certain aspects of last October's National Metal Congress, and it led to the doubtful compliment of a second request to "cover" the 19th A.I.M.E. Openhearth Conference in Pittsburgh, late in April. It turned out to be harder to condense items of metallurgical interest from the meetings of the Openhearth Conference than glean items of openhearth interest from the National Metal Congress. Many of the benefits of both groups result just from concentrating men of the same interests and letting them find out about the problems that are causing the most worry and possibly also answer a question for someone else. All of this of course never appears in the published minutes.

One fruit of this long series of conferences is the book on Basic Openhearth Steelmaking, just published. It is no coincidence that most of the information in this book simply was not known in 1925, when the first conference was held. Many of the results brought together in this book were reported at these meetings; most of the chapter authors are members of the Committee. There are a few men who discount the value of meetings and books with this unanswerable fraction of the truth, "You can't learn the art of steelmaking by attending a meeting or by reading a book." This attitude calls to mind a story about a book salesman who was attempting to interest a farmer in a marvelous encyclopedia of agriculture. The farmer said, "I don't need to buy a book to teach me how to farm better because I am not now farming nearly as well as I know how to." So in this sense a new book on steelmaking is not needed, but a saner view is that every technical and practical man interested in the basic openhearth process will find it valuable to read and to hold handy for future reference.

Production — The discussion of the relation of openhearth production to mill schedules was

opened by a review of the problem by Erle G. Hill, assistant general superintendent of the mammoth Gary works. His remarks were introduced by a three-word summary which has been used repeatedly by some in mills smaller than Gary to describe their smaller problems. The summary, although succinct, colorful, impressive and descriptive, will not be quoted in this report, primarily because it falls outside the realm of polite words. Dr. Hill concluded with an involved review of the relations among the various ways of referring to percentage of capacity operations. Between these two extremes of expression were packed many gems of practical wisdom.

In continuing this discussion Gilbert Soler, who is manager of research and mill metallurgy for Timken Steel and Tube, pointed out that an increased ingot production from new equipment in the openhearth had often been given no place to go, in the sense that there had been no parallel increase in capacity in soaking pits and blooming mill. Another aspect of this problem, mentioned by Henry J. Forsyth, mill metallurgist for Republic Steel Corp. in Buffalo, is the importance of controlling ingot surface by ladle deoxidation, nozzle and mold practice, and pouring temperature. Prevention is better than removal of defects. Depending on the soaking pits to scale off light defects involves such long heating cycles that this practice is not consistent with maximum production.

Some of the favorable aspects of the present situation are that consumer specifications are less inclined to be too narrow; there are more applications available for off-analysis heats; and large tonnages are frequently made on one grade thus establishing a standard practice.

Repairs According to Schedule

James McCloud and Clyde Denlinger of Bethlehem's Lackawanna plant both stressed the need for a scheduled furnace rebuild in keeping the shop at maximum production. Harry R. Coulson of Bethlehem's Johnstown plant mentioned how a shortage of men upsets the plans. The only way to get maximum tonnage is to organize a set schedule and stick to it regardless of cost. Sometimes the schedule requires that a furnace be taken off for "repairs" while it is still working well.

Personnel — A welcome return to old times was the reappearance — even as pinch hitter — of General Chairman Leo F. Reinartz (who is manager of the Middletown Division of American Rolling Mill Co.) as author of a paper on "The Foreman — Key to Production". It contained many nuggets of inspiration from a wide variety of sources. One example will be given: "A great deal of good can be done if one is not too careful who gets the credit." In this general topic W. H. Yeckley (openhearth superintendent of Brier Hill Works, Youngstown Sheet & Tube) asked an important question that never was adequately answered: "What can be done to insure the loyalty of the junior melter who is down-graded by the return of soldiers to their old jobs?"

With increasing use of automatic controls the statement is sometimes made in jest that soon the first helper can be replaced by a robot, or that one man can run two furnaces, which is the same idea in less radical form. It has been estimated that the results of an openhearth shop are determined by the personnel, raw material, equipment and layout, with an importance of 40, 30, 20, and 10 — suspiciously round numbers! — assigned to each of these factors. The question may be asked, "How does increased use of automatic control affect the relative importance of personnel and equipment?" An authoritative answer can be given by a man who has furnaces equipped with a large number of meters and controls. J. N. Albaugh described the equipment of the new 400-ton tilting furnaces in Republic's alloy steel plant at South Chicago, and then stated that in his opinion personnel is still just as important a factor as ever in securing the best performance from any given equipment. (A point that is sometimes overlooked is that the men need education in the use of new equipment.)

Chemistry and Physics — It is perhaps not widely known that numerous acid steel makers are financing a cooperative research program under the general direction of G. R. Fitterer, head of the metallurgical department at University of Pittsburgh. He gave a brief account of the work under way, and said that a useful new "fluidometer" had already been devised (available as yet only to the members of the group). It arouses curiosity as to the principles involved, and whether it could be used for basic or blast furnace slags.

At another discussion of slag-bath relations in the basic process, each of the elements carbon, manganese, phosphorus, sulphur and chromium was considered separately. One point made by B. M. Larsen of U. S. Steel Corp.'s Research Laboratory concerning sulphur is the importance of small increases over its normal amount. Plant practice is established to remove a certain unavoidable amount of sulphur. The last 10 lb. are much more detrimental than the first ten, in the sense that it will be more effective in raising the proportionate amount in the metal. Kish from

blast furnace or mixer was mentioned as a source of sulphur that had better be kept out of the openhearth.

The importance of small amounts of hydrogen and nitrogen is just coming to be realized. It is easy to mistake the position of the decimal point when several significant figures are preceded by three or four zeros, and at best this system is cumbersome even though understood correctly. (Page George Motock, director of Republic Steel's research staff, who was among the first to insist on the precision of hydrogen determinations to what were then an unheard-of number of decimals.) Possibly an arbitrary agreement could be established in which "one point" of hydrogen would be 0.0001%.

Problems in Combustion

Two of the formal papers on this topic had been printed and circulated in advance in pamphlet form — an innovation, and a great change from the early Conferences which were so much off-the-record that proceedings even in abstract were not published after the event. It is a fact that Americans — almost unanimously, and even those who are most vocal in all kinds of man-to-man shop talk — become stage struck and tongue tied in a meeting with more than six in the audience. That poses a difficult problem to meeting-managers. When they arrange for a written, formal paper, the audience pictures itself as a group of students and the lecturer as a professor, and who are they to argue with the professor? If the meeting-manager arranges for no formal discussion but merely sets up a question for debate and selects a chairman who knows something about the problem, then the chairman finds it necessary to pinch-hit as a lecturer and then single out men from the audience by name and almost use physical force to get them to the front to make any comment.

But to return to the meeting that considered combustion problems. The paper by Gilbert E. Seil, now of Day and Zimmerman, Inc., drew general interest. There seems to be general agreement as to the analysis of the characteristics of combustion, for there are several charts showing approximate flame temperatures under various conditions of preheat and excess air. There was not such general agreement with the proposal for a series of burners directed *across* the width of the bath. This idea is something to watch; on first impression it does not appear any more radical than top firing which has proved feasible under certain conditions.

The other preprinted paper on combustion was by Mr. Seil's associate Robert A. Noor which took a glance at furnaces as they may very well be constructed in 1965.

A good description of a practical approach to combustion problems was by A. J. Fisher of Bethlehem's Sparrows Point plant. He finds that burners can properly be adjusted according to the total radiation of the flame, which of course is the result of the combined effect of temperature and emissivity.

Robert Sosman, the versatile physicist at the Steel Corp.'s Research Laboratory, has a way of presenting the fundamentals of a problem which is indeed a pleasure to hear. After some pertinent off-the-record suggestions he stated flatly that flame temperature cannot be defined. What cannot be defined cannot be measured — at least it can't be measured in such terms that the results have any useful meaning. The four definite factors that determine the characteristics of a flame are: *(a)* The temperature of the carbon particles, *(b)* the temperature of the CO_2 and H_2O in the gases (the temperature of the oxygen and nitrogen is of no direct importance), *(c)* the density or pressure of the gases, and *(d)* the linear thickness of the various layers in the flame.

Refractories and Fluxes — There was considerable discussion of the current performance of refractories. Some felt that bricks now are definitely inferior. Others are inclined to think that it is not fair to blame the bricks for short life, because they are now, more than ever, subject to abuse, hard driving, and plain carelessness of less experienced operators. Still others state that refractory consumption in their shops has not increased to any appreciable extent. Surely such a discussion provides an excellent background for some real thought and checking up. A similar useful exchange of experiences was brought out in replies to questionnaires that were circulated before the meeting and ably summarized.

Some spontaneous discussion reminiscent of the earlier conferences developed around the use of substitutes for spar. It appears that the best substitute for spar is a purified form of spar. This arguing in a circle is not as ridiculous as it first appears. The fact is that calcium fluoride is so good a flux it seems to be unequaled. Spar concentrate in the form of pellets, to avoid being carried down the flues, is about the most satisfactory way to supplement the present low grade gravel spar. Aluminum dross does not replace spar in all respects, but it can be used to conserve spar and save money. Salt is so highly volatile the fumes form a hard glaze which freezes the flue dust to the checkers, and at one plant even plugged the waste heat boiler.

Purchase of Steels on Performance Rather Than Analysis

CHAIRMAN of the group meeting at last October's National Metal Congress on the "Purchase of Steels on Performance Rather Than by Analysis" was Col. H. H. Zornig, Director of the Laboratory at Watertown Arsenal. In his opening remarks, Col. Zornig spoke of the various aspects of the problem of purchase under specifications. "Quality" is desired, but quality is the degree to which a material possesses the characteristics necessary to fulfill the functions to which the article is intended to be put. First it is necessary to determine the characteristics which are desired in a given material for a given part, and then by tests outlined in detail to determine the degree to which these qualities are met. Consequently it is of the utmost importance to delineate, by examination of the functioning of the part in service, the quality characteristics which are necessary. Before anything can be bought on performance, it is obviously necessary to know what performance is required for the given service. This may be the most difficult part of the whole job.

Dependable Performance Is the Prime Consideration

By Glen C. Riegel
Chief Metallurgist
Caterpillar Tractor Co.

LET US approach this problem with a query that may, at first sight, seem somewhat distant from the subject: "On what basic economic principle does business rest?"

If Mr. Jones has saved up several thousand dollars and can persuade a number of other associates who have likewise saved up sums of money to join with him, they incorporate a manufacturing company and go into business. These investors become the stockholders who furnish the money for ground, buildings, machinery, and the initial purchases of raw materials.

As soon as the business obtains customers, the money received from these customers of the Jones Mfg. Co. becomes the stream of money out of which it dips for paying the operating expenses consisting of salaries, wages, taxes, interest (if any) to the stockholders, and the cost of indirect and direct production materials. Therefore, the manufacturer exists only because the customer makes use of the product.

Next let us inquire briefly as to the true role of the customer.

Let us assume that the Jones Mfg. Co. becomes a maker of steel. Then, logically, the Jones Mfg. Co. can only exist if there are customers who use the steel to satisfy some human need. Then, those who fabricate steel into some "end use" such as railroads, bridges, trucks, tractors, and what not, are, in a like manner, financed by the streams of money which are obtained by them from their customers — the users of those products.

It follows therefrom that, actually, the manufacturer of a useful product is but the temporary custodian of the customers' money.

Continuing with the catechism:

Q. What Is the Manufacturer's Moral Obligation to His Customers?

A. In the early evolution of business there was coined an expression, *caveat emptor* — let the buyer beware. All the risk fell upon the buyer. If he bought a half-dead horse, that was the

buyer's hard luck. Today, the manufacturer who wishes to stay in business must become the guardian and custodian of the customer's money or he will soon exit from the business world. In other words, to ignore the customer's best interests is a sure road out of business.

Q. What Does the Customer Buy?

A. He intends to buy a use, or a service, or (if a machine) a performance. If you buy a suit of clothes you expect that it will protect you from the elements — the sun's blistering, the winds' cold, the briars' scratches. If the suit rips, tears apart, and wears out quickly, you say it was "no good" because you received less than the expected performance. It is fundamentally *performance*, therefore, that you as a customer see in the suit before you buy it. It may have elegance, style, and all that which are also uses to you, but the true fact is that you bought the suit as an extra layer of hide.

Q. What Element of Performance Is the Most Important in a Machine?

A. Granted that a machine is known to be of good design and capable of performing a useful service, by what main factor is the actual worth measured? Would you not quickly say, "dependability"?

If you buy a new tooth brush and after the first few times you use it the bristles begin to come out in your mouth, you are provoked at its lack of dependability. If you buy a new automobile (many of us wish we could!) the worst disappointment comes when you must make a train and have but limited time, and the contemptible piece of junk won't start! It lacked dependability. Broadly, then, the foundation upon which performance rests is *dependability*. There must be a response of service when you ask for it.

Q. How Can We Ensure Dependability in a Machine?

A. Manifestly, the dependability of a machine, of which the human body is a crowning example, depends upon the integrity and performance of its individual members. This is none the less true of inanimate machines, consisting largely of steel members. The deceased occupants of the wrecked vehicle on the bottom of the mountain chasm will never know that the "gyp" steering knuckle king pin made of brittle screw stock was non-dependable. In such an event some snide manufacturer's conscience ought to trouble him.

The best test is undoubtedly that of the complete machine. Obviously, it is impossible to use every machine as a test model, or to use some member of an operating machine as a test for every new lot or mill heat of steel prior to fabrication into parts. Fortunately, there are certain qualities of steel, or characteristics, which may be determined from test samples and from which test data relative to performance may be predicted with a fair degree of accuracy.

Q. How Can We Predict a Steel's Performance From Tests?

A. Since we have concluded that dependability is the most desired performance characteristic, the problem is to predict this dependability. In general, dependability is avoidance of failures. That leads to the subsidiary question: "What types of failure of mechanical structures are usually revealed by service?"

1. Do well-designed machine parts pull in two as in a tension test?

2. Do most of our part failures twist in two as in a torsion test?

3. Do many of the mechanical failures represent crumpling as under compression?

4. Do we not most frequently see the progressive type of failure, which we call fatigue? (In the last stages of the fatigue failure, a sudden separation may take place or the fracture may exhibit final separation as by torsion or tension.)

5. Probably the next most frequent type of failure is the sudden separation which we call a brittle fracture.

While fatigue testing doubtless approaches more nearly the conditions of service than do many other types of test, unfortunately a knowledge of the fatigue strength of a steel test piece serves little useful purpose in predicting the liability of an *actual* part made of it to fail in service. For example, fatigue tests of the heat treated wire for the main cables of the Ambassador suspension bridge were not true criteria of the liability to failure in service. Fatigue tests made from a broken crankshaft of a wrecked airplane do not explain why that particular crankshaft failed. The difference in size, geometrical form, surface qualities, and localized incapacity to absorb additional stress, make the machine component too utterly dissimilar to the little, polished, fatigue specimen run in the clean, warm laboratory to be of great practical worth as a guide for designers.

Since the results of most fatigue tests bear an approximately constant ratio to the ultimate strength of that same steel, and since ultimate strength is quite accurately predictable from indentation hardness tests, the latter have yielded the most useful and practical information. The widespread acceptance of hardenability testing is evidence of the usefulness of this criterion for predicting the dependability of a machine mem-

ber, insofar as strength in tension, torsion, or compression is concerned.*

As most of you are aware, the similarity of strength alone of two steels will not predict how well such steels will behave in service. Normally, we should not suspect that mild steel, with its known capacity for local yielding without appreciable increase in strain with a rise of stress, would ever fail with a sudden and brittle fracture, but it can and does, and two different mill heats of mild steel of the same strength may show entirely different behavior under the same conditions of stress in the presence of a change of section and at reduced temperature.

For example, a 9-in. ship channel, welded into a box section and forming the main frame of a heavy road machine, broke in two like brittle cast iron when the weight of the machine dropped from a 10-in. curbing. The temperature was 20° below zero. The *strength* of the steel was slightly superior at the sub-zero temperature, when compared to tension tests taken at +75° F. Ductility factors were similar at both temperatures, that is, about 43% elongation in 2 in. and 52% reduction of area.

However, the cohesive strength of this steel in the presence of a notch, measured empirically by the keyhole Charpy test, dropped from 36.0 ft-lb. at 75° F. to 2.5 to 3.0 ft-lb. at —20° F. and to 1.0 to 1.5 ft-lb. at —40° F. Thus, we have here a behavior which was not predictable from the hardness or a hardenability test. Yet, the dependability of the machine members made from this 9-in. ship channel was grossly non-dependable in the very usage for which it was bought. Someone facetiously remarked that the machine should have been sold to remove snow in the tropics instead of in Canada.

Conclusion — If so-called performance tests *in advance* of steel fabrication can be correlated to the enhancement of durability and dependability in service, it is proper to make such tests at the earliest possible stage in the conversion of steel to finished parts to avoid misuse or loss after fabrication has proceeded so far that scrap and remelting is the only recourse. Certainly, no producer of raw material such as steel is eager or willing that the parts or machines made from his steel should fail from lack of dependability. On the contrary, much of our industrial progress has come from the continuous improvement in the dependability of fabricated steel.

*Mr. Patton developed the thesis, at this same round table discussion, that there is little difference beween strength and ductility of any engineering alloy or carbon steel, despite variations in its composition, when it has been fully quenched and then drawn back to a given hardness level. See page 1094.

Correlation of Tests With Performance

ACCEPTING Mr. Riegel's train of thought, J. Almen next made some general remarks on the problem of correlating laboratory tests to performance in service. Obviously some rapid preliminary test (or tests) is necessary to separate the sheep from the goats, to exclude the thoroughly undependable material, or even to insure that the current receipts are substantially similar to the materials received last year and which have given no trouble either in fabrication or later use. Correlation of such routine tests, or any specialized laboratory tests with performance is very difficult. No doubt the only sure way to determine the acceptability of steel for a given use is to make the part and then to determine *by performance* whether or not the part is acceptable. Since this is an impossible requirement for an *acceptance* test, the next possibility is to attempt to simulate the conditions of service in the laboratory. Such simulations, however, are often difficult to interpret and sometimes give little information as to the performance of the steel. Definite examples were cited, among them some that were discussed at length in Mr. Almen's series of articles starting in *Metal Progress* for February, 1943.

The speaker then pointed out that the number of failures of a given part that can be tolerated (as long as the failure does not endanger life or involve a large financial loss) depends upon the numbers in which such parts are produced. After a certain amount of experience in production and the service of a given article, it is then possible by observing the fractures in that part to attempt to reproduce such failure in the laboratory. Oftentimes, the tests which produce this failure are very dissimilar from what would be expected from the examination of the working stresses. However, with a sufficient amount of experience and using this method, it is quite possible to set up laboratory tests and determine the relative acceptability of metals. A case in point is the engineering appraisal of ball bearings, in which the loads by which they are specified have nothing whatsoever to do with the calculated stresses, but have to do with their relative service life. The best if not the only way to determine the relative acceptability of steel for a given part is therefore to accumulate service data and systematize this information. When tests can be formulated that give the same incidence of failures and produce the same type of fractures, then these tests will predict the performance in the users' hands.

*Available only in the form of reporter's notes.

Present and Proposed System of Specifications

By Ernest E. Thum
Editor, Metal Progress

T IS APPARENT from what the preceding speakers have said that, desirable though a ecification based on performance may be, it is ceedingly difficult to establish an acceptance t that will measure the expected service. Mr. egel also mentioned the desirability of using se tests as early in the line-up of manufactur- operations as possible. This is equally true the steel making processes, and is the prime son why chemical specifications rule. Samples the steel can be analyzed, and the heat com- sition predicted fairly accurately, before the tal is out of the furnace and while is in such a condition that some ective corrections may be made. It n therefore be predicted that close emical control will continue to be ercised by the steel maker, even ough the analysis be not mentioned the customer's specification.

As a matter of fact, a major part American steel in peace-time is ught with scant attention to its precise analysis or to put it somewhat more correctly, the alysis is distinctly secondary to some physical t, surface condition, or dimensional tolerance. eryone knows that deep drawing sheet is gely adjusted — by the steel mill — to the ecific job that has to be done, and the draw- lity is much more closely related to surface, at treatment, and age-stability than to content the five ordinary alloys — carbon, manganese, icon, sulphur and phosphorus. Most wire, nail d bolt stock is made for easy fabrication. Users pipe are more interested in its bursting ength, thread dimensions and corrosion resist- ce than they are in the steel's analysis. Rails principally judged by the drop test; while emistry is incidental, more attention is given soundness and toughness. The A.S.T.M. speci- ation A10-39 for mild steel plate gives the sile properties in detail; the only chemical ecification other than for copper is a maximum phosphorus and sulphur.

One might conclude therefore that, in general, the tonnage and carbon steels (even the structural silicon steels and nickel steels) are usually accepted after they pass some token test supposed to represent ability to perform.★ On the other hand the emphasis on analysis arises in the engineering carbon and alloy steels which are to be used in heat treated condition, or the high carbon and alloy steels used for corrosion, heat or wear resistance. It may be recalled, also, that the S.A.E. list of chemical specifications was established to bring some rhyme and reason into a growing list of manufacturers' trick, trade names for alloy steels.

Conditions are said to be less onerous in England and on the continent. If so it is because a larger percentage of the metal is sold on trade name (steel maker's implied guarantee), for the published specifications are not so different from American.

For example, German specifications (DIN, so-called) range from very simple to very restrictive. Forging stock, Grade A, lists no analysis of any sort; DIN St 00:11 lists no required properties, whereas St 37:11 specifies tensile properties only. Grade B forging stock limits carbon, phosphorus and sulphur, and states strength and elongation as well. At the other end of the range we find five classes of chromium-nickel alloy steels in DIN KrG601, for high strength structural and mechanical steels, each with a range of tensile strength, yield strength, and elongation, and maximum hardness, together with complete chemistry. Fortunately for the steel maker, the difficulties connected with meeting combined physical

★At this meeting, Earle C. Smith, Chief Metallurgist of Republic Steel Corp., said that in 1939 less than 25% of the steel manufactured in America was specified by chemistry alone. Two-thirds of the bars and one-half of the strip were sold on properties. In present war-time, about half of the present steel production has some important chemical requirement. In addition to this, much of the bar and alloy stock has some additional important test to meet, such as internal soundness or hardenability. To emphasize the large amount of physical testing required in the acceptance of ordnance steel, Mr. Smith remarked that the new Republic alloy mill just going into production in South Chicago, capable of producing 4000 tons of steel per day, has installed extensive crane and conveyor equipment in the laboratories, for some 100 tons of this steel will be consumed *every day* in physical, chemical and metallurgical tests and scrapped from these same tests. It would seem to be about time for the statistical analysis experts to move in, when 2½% of the output made in mass production must be used up as a sample to insure uniformity and acceptability!

and chemical properties are mitigated by establishing rather wide chemical tolerances, and a footnote saying "slight deviation from chemical composition is not grounds for rejection as long as physical values are sufficient".

So much for the present practices. They have grown up gradually, largely as a result of give-and-take between steel maker and customer. Any large change looking toward a substitution of performance tests will encounter three complications:

First, the problem is complicated from the purchasers' viewpoint. The small outfit with only rudimentary testing equipment looks at the matter differently than does Caterpillar Tractor, for example, which is geared to perform an extensive series of acceptance tests in the 24 hr. a heat of steel is held in the soaking pits before rolling. The small consumers (and many large ones) look to the steel maker to perform most of the metallurgical testing, and to be the source of help when anything goes wrong with the product, or of information when new demands are to be met.

Second, the problem is complicated from the steel makers' standpoint. None of them will knowingly ship unsuitable material; their own reputation and good will is as much an asset as their customers' are to them. Nevertheless, the steel maker is a mass producer, and he must get quick clearances and release of heats of metal, else his plant and storage yard is quickly congested. *Delays* are generally to be expected from performance tests; an extreme example is heavy armor plate which is held until samples are tested for ballistic properties.

Finally, the problem is complicated from the testing engineers' standpoint. This has already been developed by previous speakers. It might be added that the tensile test, so omnipresent in specifications, is primarily an easy test for *uniformity* rather than for strength. Actual performance of steel parts in war-time (ordnance) involves ability to withstand one or a few large overloads. Peace-time equipment fails from wear, rust, or "fatigue". Yet the testing engineers are by no means agreed upon a laboratory impact test, nor is there any accepted wear test, nor any quick corrosion tests. Finally, as Mr. Almen will agree, endurance tests should be made on finished parts and assemblies rather than the small sample, because most service troubles come from mechanical or design errors rather than metallurgical faults.

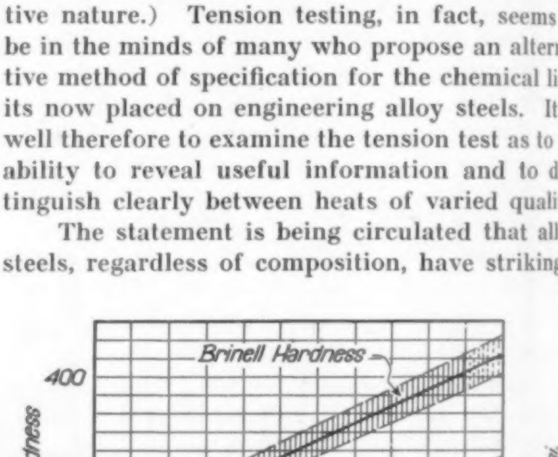
This is the Gordian knot that must be cut by joint action of producers and consumers before steels can be bought on performance!

Equivalence of Hardened Steels When Tested in Tension and Impact

By Walter G. Patton
Statistician, Climax Molybdenum Co. of Michigan

TENSION TESTS are made more frequently of metal than any other test — as far as specification and acceptance is concerned. (Control in fabrication is largely exercised by hardness measurements, because of their ease and non-destructive nature.) Tension testing, in fact, seems to be in the minds of many who propose an alternative method of specification for the chemical limits now placed on engineering alloy steels. It is well therefore to examine the tension test as to its ability to reveal useful information and to distinguish clearly between heats of varied quality.

The statement is being circulated that alloy steels, regardless of composition, have strikingly



Relation Between Tensile Properties and Hardness

similar tensile properties when fully hardened and tempered. At the risk of being repetitious — but with the hope that metallurgists will examine this statement for the great potential value it contains — let me recall to your attention a statistical study of tensile tests on 409 heats of S.A.E. and NE steels, published in *Metal Progress* for May, 1943. The general summary is contained in the drawing on page 1094. Obviously, if one can accept the premise that all fully hardened, low alloy steels have similar tensile properties at equivalent hardness levels, it is no longer necessary to pull a great many test bars to determine the interchangeability of steels *insofar as their tensile properties are concerned*. This permits the metallurgist to concentrate on a study of factors like hardenability, machinability, uniformity of response to heat treatment, and resistance to fatigue failure and occasional overloads — all characteristics of steel which must be proved before the interchangeability of two alloy steels can be established.

When the yield point of fully hardened steels is plotted against tensile strength the result is a straight line (or band) up to a strength of 200,000 psi. The original publication shows that two-thirds of the results fall within the range of ±5% of the "average line", and this is as good a fit for any one type of alloy steel as for another. Up to 200,000 psi. tensile strength, no individual alloy steel develops consistently high or low values; further, no alloy combination in the fully hardened and tempered condition has a consistently higher or lower yield point.

This analysis of a great many results from various reliable laboratories on steels made by all commercial processes indicates that composition has small if any influence on the yield point (other than in its indirect effect through depth of hardening). Until we know more about it, it seems hazardous to ignore the many factors *other than composition* that may exert at least as strong an influence as the analysis of the steel in determining yield point. One scarcely need add that in no case should we attempt to judge the yield point of a given type of steel without an adequate volume of test data.

As shown on the graph, the relationship of Brinell hardness to tensile strength can also be regarded as linear up to about 250,000 psi. The results may be not too trustworthy beyond 500 Brinell. These are probably the least controversial of any statements I may make on this general subject.

From a similar study of plotted results of reduction of area and elongation (the so-called "ductility" factors) the following conclusions can be drawn: From 100,000 to 200,000 psi. a range of ±10% from a smooth average curve includes 90% of the ratios for reduction of area, and 80% of the ratios for elongation. Above 200,000 psi. results are very erratic, which is in agreement with the earlier findings of Boegehold and others. Again it should be emphasized that no family of alloy steels is consistently high.

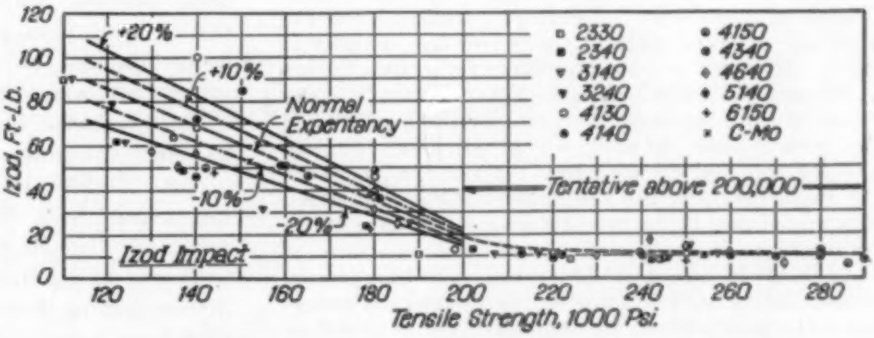
Steels With Intensifiers — Many users are interested at the moment in the properties of steels treated with intensifiers. A similar study was made for steels which had been so treated. At tensile strengths up to 200,000 psi. (400 Brinell) these steels showed no appreciable differences in properties from other alloy steels. At high tensile strengths (290,000 to 310,000 psi.) the *average* ductility of the specially deoxidized steels was perceptibly higher than it was for S.A.E. and NE alloy steels. This strictly preliminary result indicates that if there is anything unique about the tensile properties of steels treated with intensifiers, it will probably lie in the high hardness range.

Notched-Bar Test: The problem of Izod impact requires special consideration. A large number of test results were not available, so the lines shown on the chart below should be considered as strictly tentative. The following observations are pertinent:

1. The Izod chart is the only curve in which the scatter of data, as plotted on a basis of foot-pounds, is greater at the left for low tensile strength than it is at the right of the diagram, for high tensile strength.

2. Below 200,000 psi. tensile strength, a spread of ±20% includes only about two-thirds of all the tests reported.

3. No type of fully hardened steel shows an outstanding advantage over any other type.



Check Chart of Izod Tests, as Related to Tensile Strength

This wide fluctuation in impact test results is not new with the National Emergency steels. The S.A.E. steels have been in use for many years, yet even today there is not agreement as to their respective impact properties. In fact, the impact properties of alloy steels seem to be a function of the number of sources reporting Izod data; the more sources, the wider the fluctuation in results. It follows that we should exercise restraint in drawing conclusions from the few scattered impact data that usually come into our hands. Also the fact should be recognized that impact strength may be of small importance in a part which fails from fatigue.*

There are some of us who have come to believe that, in the past, too much emphasis has been placed on the individual contributions of alloying elements in promoting ductility of fully hardened and tempered steel. With great sincerity, we have attributed unique powers to specific alloying elements which we are unable to justify after unprejudiced examination of several hundred heats. The ductility of two heats of fully hardened steel having different analyses may differ considerably — but so may the ductility of two heats of a single type of steel.

*Various questions were asked from the floor concerning the relation between Izod and Charpy impact tests and the temperature at which these tests should be performed. It was pointed out that for aircraft steels, the impact tests are specified down to −65° F. and up to 200° F. Answers from the panel indicated that while there is no ready conversion between the Izod and Charpy results, each moves parallel to the other with respect to the variables of steel making and processing. Either test can be used, even though the absolute magnitudes of their results for the same steel differ. Mr. Riegel was of the opinion that tensile impact tests are very poor criteria of the behavior of steels to be used in structures and are poor means of differentiating between materials which are brittle or ductile in the notched bar impact test. In answer to a question from the floor, as to whether or not a steel within the chemistry range ordinarily specified could be depended upon to have consistent properties, Mr. Smith pointed out that the ordinary chemical analysis does not usually include those details which differentiate between the various steels within a given chemistry range. Brittleness in steels may, for example, depend upon the presence of some element for which no analysis is made. Nitrogen and arsenic make for brittle failure if present in "large" quantities and these two elements are not generally reported by the analyst. At the present time, he said, we do not know what to analyze for, nor do we know the relations between the impurities and the resultant physical properties. It is hoped that in the near future we will have better information as to the effects of small amounts of impurities on physical properties, but the present specifications of chemistry within the normal ranges are not a guarantee of the dependability of steels for a given service.

It seems advisable, in considering the tensile properties of low alloy steel, that we recognize the following eight points:

1. We should recognize that, under the most favorable conditions, the information we need to have about the interchangeability of two alloy steels is only partially available from even a large number of tensile tests.

2. We should recognize that tensile tests on single heats of steel can, at best, only reflect the quality of that specific heat of steel. Single heat test results merely add a single series of results to the volume of data required to pass sound judgment on the properties of steel.

3. We should recognize that the tensile properties of alloy steel will fluctuate from heat to heat and the *range* of such fluctuations, while substantial, is predictable.

4. We should recognize that many of us are inclined to draw sweeping conclusions about the tensile properties of alloy steel from only a few scattered test results. We are tempted to explain any and all differences in mechanical properties, particularly ductility, solely in terms of variations in alloy content and some of us yield too easily to this temptation.

5. We should recognize that, in interpreting tensile data, we should always be careful not to attribute to *unique* alloying effects those variations in the properties of steel that can be better accounted for by greater hardenability or variation in steel making practice.

6. We should recognize that, at tensile strengths above 200,000 psi., the effects of trapped stresses and retained austenite may vitiate our ability to get consistent test results.

7. If we recognize that all fully hardened steels have virtually the same tensile properties at equivalent levels of hardness, we may assume these properties are predictable. Taken collectively, the factors of hardenability, machinability, distortion, response to heat treatment, resistance to fatigue failure and response to welding should, then, carry more weight than tensile tests in determining the relative merits of alloy steels or their possible interchangeability. If industry can assume this position, the elimination of a large amount of tensile testing will give the researcher considerable time to develop standardized tests for factors which *will* help us better to select the proper steel for a given part.

8. Finally, it seems logical that the individual tensile test is best interpreted as merely reflecting the *quality* of a heat of steel. Such tests are of limited value — if not useless — for distinguishing between two *normal* alloy steels that have been fully hardened.

Appraisal of Steels by Their Hardenability

By Walter E. Jominy
Chief Metallurgist
Dodge Chicago Plant: Chrysler Corp.

THE HARDENABILITY TEST, as a means of finding steels of equivalent hardening power, has now been used by at least a small group of metallurgists for more than five years. The test has been brought into widespread use rather quickly because of the war emergency, the shortage of alloying elements, and the necessity for using substitute steels. For the past two years the test has been on trial as a method for determining which of the so-called alternate steels can be substituted for the old S.A.E. steels.

Viewed as an overall picture, I think it can be said that reliance on the hardenability test, using the end-quenched specimen, has been justified by the rather gratifying results which have been obtained with the National Emergency steels. Of course, the reason for the success of those NE steels is primarily because of the intelligent handling of the problem on the part of the War Production Board, the steel producers, and the steel users. Nevertheless these groups used the end-quench hardenability test as the means of determining the possibility of successful substitution of one steel for another as a first consideration.

Although this test has been so successfully used, it is quite easy to make costly errors in its application. It is easy to confuse hardness with hardenability and to assume that if proper hardness is obtained, all engineering properties of the steel will be satisfactory. This is not true, because in addition to proper hardness it is necessary to have correct microstructure.

In a general way, I believe we can say that the hardenability test gives a fair indication of engineering properties, and very little indication of fabrication properties. It tells us nothing about tendency for flaking or ease of forging. It is quite possible to have too much copper or an overdose of boron which will produce red shortness in the steel under test without any indication of it in the hardenability test, except perhaps the added hardenability from these elements. The end-quench test gives us very little hint as to machinability, although it does give a pretty good idea about the ease of annealing, for the higher the hardenability, the more slowly the steel must be cooled to produce the desired low hardness for machining or cold working. This is self evident because the higher the hardenability the more slowly must the steel be cooled at the knee of the S-curve.

So far as the engineering properties are concerned, if we make the stipulation that the carbon content be the same, then I believe we are fairly safe in assuming that for steels of like hardenability the tensile strengths and fatigue resistance will be comparable. We will not be able to predict such properties as resistance to wear or strength at high temperatures — and of course there is no correlation between hardenability and resistance to corrosion.

Care should be exercised, when attempting to find substitute steels by the hardenability test, to be certain that the carbon contents are not too widely divergent and to have such steels as are being tested representative of their respective type analyses.

The error in having rather widely divergent carbon contents may result in similar hardness but dissimilar microstructure. Carbon adds both hardness and hardenability. The effect on the hardenability is relatively small; the effect on the hardness is relatively great. A hardness, for example, of Rockwell C-40 using a 0.90% carbon steel has an entirely different meaning from that

Table I — Variation of Ideal Hardenability With Spread of Analysis

Steel	Composition Range	Chemical Composition						
		C	Mn	Si	Cr	Ni	Mo	D_{Ideal}
S.A.E. 4140 Grain Size 6	Minimum	0.38	0.75	0.20	0.80	—	0.15	3.38
	Mean	0.405	0.87	0.27	0.95	—	0.20	5.05
	Maximum	0.43	1.00	0.35	1.10	—	0.25	7.60
S.A.E. 4340 Grain Size 6	Minimum	0.38	0.60	0.20	0.70	1.65	0.20	4.75
	Mean	0.405	0.70	0.27	0.80	1.82	0.25	7.00
	Maximum	0.43	0.80	0.35	0.90	2.00	0.30	10.3
N.E. 9442 Grain Size 6	Minimum	0.40	1.00	0.40	0.20	0.20	0.08	2.69
	Mean	0.42	1.15	0.50	0.30	0.30	0.115	4.19
	Maximum	0.45	1.30	0.60	0.40	0.40	0.15	5.89

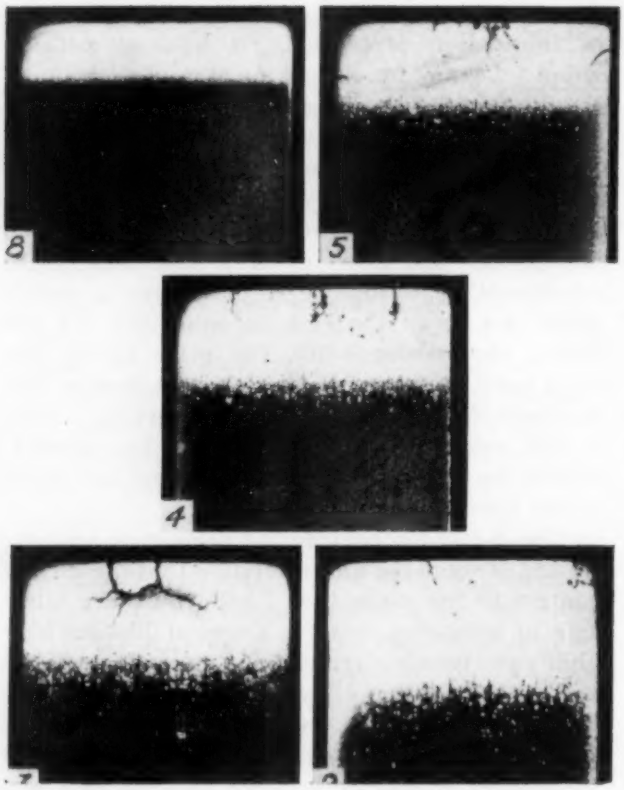


Fig. 1 — End-Quenched Bars of a Single High Carbon Steel, Split Longitudinally and Etched to Show Depth of Fully Hardened End, as Affected by Grain Size at Time of Quench. (*C. R. Austin, in* Transactions ⊕, *September 1943, p. 533*)

same hardness when using a 0.12% carbon steel. An entirely different microstructure is indicated in these two cases. In comparing carburizing steels, a difference of two points of carbon quite definitely affects the results.

To be certain that steels tested are representative of their respective analyses is self evident. One must be careful about grain size at the time of quenching, if a proper appraisal of the hardening power of each of the elements is to be made and the effect of residuals noted. For example, the table on page 1097 shows the rather wide range in computed hardenability that is obtained when all the specified elements are on the low side or on the high side, to say nothing of unreported residuals. The hardenability index listed under D_{Ideal} is that calculated by Grossmann's method.* (There are those who feel that much data must be obtained to be certain that the factors used by Grossmann are accurate; however, I believe the table shows approximately the hardenability ranges that may be obtained with the steels listed.) From this it appears that if we happen to be comparing S.A.E. 4140 with all the elements on the high side of the specification, and S.A.E. 4340 having all the elements in the middle of the specification, we would come to the conclusion that 4140 has deeper hardenability than 4340, which we know is incorrect.

Joseph Field has gone a step further than Grossmann and figures hardenability by calculating the end-cooled curve. (See *Metal Progress*, March 1943, page 402.) He claims to obtain good correlation between the calculated variations with curves experimentally determined. At any rate, once we have by any means the hardness-distance curve for the end-cooled specimen, we have useful and practical information.

To show the effect of grain size on hardenability, Fig. 1 is presented, taken from the work of Prof. C. R. Austin of Pennsylvania State College. The light area which shows the hardened distance on a (non-standard) end-quenched bar indicates the rather wide variation in hardenability that can be obtained with the identical steel, treated so as to have different grain sizes at the time of quenching.

Figure 2 shows the cooling curves obtained with some carburizing steels. (These were obtained with the so-called L-bar, which is used on relatively shallow hardening steels.) Notice the different shapes of these curves; also that the contour of the line for S.A.E. 3115 steel is quite different from that of the 4815 steel. If, as most people believe, the 50% martensite, 50% pearlite point is at the inflection of the end-cooled curve, it will be evident that this point cannot be used as a safe indication of the point where 95% martensite occurs. In nearly all cases we are interested in the point where 95 to 100% martensite is present, because in most cases we want steel to harden fully, so as to develop maximum properties after proper tempering.

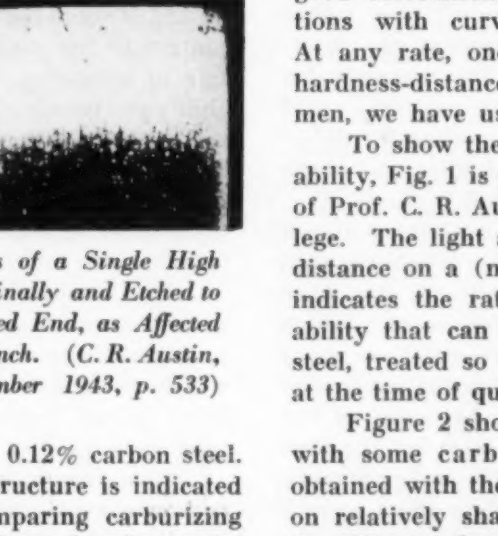


Fig. 2 — End-Quench Hardenability Curves for Four Carburizing Steels

*Metal Progress Data Sheet No. 29, 1943 Edition.

It seems almost unnecessary to say that in testing for hardenability a hardening temperature well above the Ac_3 transformation should be used. Yet a number of specifications now in use call for quenching from within the transformation range! Obviously there will be difficulties when two laboratories attempt to check each other under these conditions. Both the A.S.T.M. and the S.A.E. standard hardenability test methods call for hardening at 75° F. above the Ac_3 point.

Standard Methods of Test

Other details for making the test have been widely published. See, for example, the methods of the Steel Standardization Group, in *Metal Progress,* December 1941, page 911. Some elementary precautions might be emphasized: It is necessary to grind the specimens flat on both sides before testing and to be sure that the two flats are parallel. Furthermore, this grinding should be very slow to prevent overheating. It is also necessary to be on the lookout for decarburization during heating before quenching. [Certain questions were asked from the floor concerning the relation between the "Jominy test" and the S-curve. In answering, Mr. Jominy pointed out that the information obtained from the S-curve is much more satisfactory for general heat treating purposes. However, it is often sufficient to know merely the hardenability. With the present emphasis on annealing practice and "martempering", S-curves help the metallurgist to obtain the best possible structures from his steel for a given use.

There is not much experience as to the range to be used in *specifying* hardenability. (Ordinarily the specification would say that the steel should have a certain hardness somewhere within a given length along the end-quenched test piece.) This range or length on the end-cooled bar will depend upon whether the steel is deep or shallow hardening. If it is shallow hardening, the change in cooling rate will be relatively large per $\frac{1}{16}$ in. along the bar; if deep hardening, relatively small per $\frac{1}{16}$ in. For instance, a range of from $\frac{1}{32}$ to $\frac{3}{32}$ is easily met, whereas a range of $1\frac{1}{32}$ to $1\frac{3}{32}$ would be impossible to meet. Sometimes only a minimum requirement is given and sometimes only a maximum.

Most hardenability tests are given as an added limitation to the chemical requirements, and it is reasonable to expect that steel should not have all its elements on the low side or on the high side of the specification. The hardenability test, when properly specified, insures against such a condition.

Alloy Steel Specifications Based on Type Analysis and Hardenability*

By Greswold Van Dyke
Manager, Special Steels Dept.
Joseph T. Ryerson & Son, Inc.

CAREFUL USERS of steel have always been interested in uniformity of performance. This is the reason for the trend, over the years, to the specification of ever narrowing analysis ranges. The limit of commercial steel making has probably been reached, without reaching adequate control of hardenability. Since the important steels are used in the heat treated condition, it would seem that the logical way to specify steel would be directly on the basis of its hardenability, rather than by attempting this objective indirectly by specifying analysis and grain size more closely. Success in appraising the National Emergency steels by their hardenability has given considerable headway to this idea among steel makers and users.

There is nothing new about this method of buying steel to a hardness specification. In the early days of crucible steel and before chemical analysis was understood or used, steel was actually sold on a hardenability basis. The old methods of manufacture were imperfect and not subject to close control. It was impossible for the steelmaker to predict just how a certain batch of steel would harden before he had actually tested it. For this reason, steel was sold on the basis of hardenability after being hardened, nicked and broken. Chemical composition, grain size, and the other factors which govern hardenability were integrated by the educated eye; fracture classified the product and probably the price.

It is now proposed that, in the light of our present scientific knowledge, a more logical method of specifying alloy steels would be first to select a certain *type* of steel, and then — instead of specifying the exact chemical composition — simply require that the steel have a certain

*Not presented at the Round Table in Chicago, but released at about the same time, and neatly fits into the discussion.

specified degree of hardenability, which is, of course, also a measure of strength. This method of procurement would not necessarily mean any change in the type of alloy steel being used. Thus, if a manufacturer had been using A.I.S.I. A-3140 steel in the past, he would continue to specify "A.I.S.I. Type A-3100" but would specify the hardenability instead of a full analysis range.

In carrying the idea of specification of alloy steel on a hardenability basis to a logical conclusion, one might suggest the adoption of about 12 major standard alloy compositions which would be similar to the following types and would apply to most of the structural alloy steel tonnage now produced:

Alloy Steel Composition	Type	Suggested Identification
Nickel	2300	N-1
	2500	N-2
Chromium	52000	C-1
Molybdenum	4000	M-1
Chromium-nickel	3100	CN-1
	3200	CN-2
Chromium-molybdenum	4100	CM-1
Nickel-molybdenum	4600	NM-1
	4800	NM-2
Nickel-chromium-molybdenum	9400	NCM-1
	8700	NCM-2
	4300	NCM-3

In these 12 suggested steel types the range of alloying elements would be considerably broader than those now used in S.A.E. or A.I.S.I. specifications. Carbon, of course, would be eliminated from the specification entirely and a simple system of letters or numbers could be adopted to identify the different types.

If a quick hardenability test could be made on a heat of steel before tapping, then by furnace or ladle additions the steel could be brought to the proper hardenability range and the inconvenience and expense of off-heats would be materially reduced.

This idea may be reaching rather far into the future, but sufficient experimental work has been done to indicate that very interesting results can be secured from a cast sample by the Jominy method and that the results so obtained correspond very closely to those secured from finished bars of the same heat. (See *Metal Progress*, December 1943, page 1133.)

The time element required for making the test on a cast sample and the rate of loss of oxidizable hardening elements, such as chromium and manganese, would have to be closely coordinated. There seems to be a general thought among producers and users of alloy steel that if such a scheme could be worked out it would be worth considerable time and effort.

Problems Applying Especially to Toolsteels

By Sam C. Spalding
Metallurgical Engineer
American Brass Co.

TOOLS, possibly even more than other parts made from steel, are judged by their performance. In fact, it could be quite truthfully said that users don't care what the composition of the steel is from which the tool is made, if the performance is up to standard.

The matter then that concerns us in purchasing the steels for our tools is: What indexes or factors are available to use in selecting them? We would list them as:

1. Price
2. Chemical Composition
3. Physical Characteristics

Concerning Item No. 1, Price, of course, is always important as it is a factor in final cost. The organization I am associated with has already adopted the principle, however, that for our tools we will purchase on performance only. As we must immediately admit price has no bearing on performance, the price factor can be eliminated.

Let us now analyze Point No. 2, Chemical Composition, a bit and see what we find. If we were to gather together the catalogues of the 14 or 15 American toolsteel producers and list the chemical compositions of their various brands, it would be a very confusing and lengthy array. On the other hand, if we start to classify them by recommended uses, we find we can quite readily get them into about four groups, each having a limited number of type analyses. We thus find that almost the entire toolsteel field can be covered by a reasonably limited number of types and analyses. All that should be necessary would be to pick out the desired type, put out analysis specifications on that basis, and all would be taken care of.

In actual practice we find that this does not work. We may select what we feel is a suitable analysis of steel, and get some steel of this sort, and make up our tools. Suppose we have made a happy selection and the tool comes out well and gives what we consider an excellent account of itself. We pat ourselves on the back and say,

"There we have it". A little later we have occasion to make some additional similar tools. We find we need some more steel but when we go to buy it the lot or brand we purchased before is gone, but we can get some more of the same analysis. We do so, make up our tools, process them the same, and then — to our dismay — find they are not the same. They may crack or distort unduly in hardening. They may go through heat treatment with seeming success, but fail in service by chipping, caving in, or crumbling. I presume any of you who have made, hardened, or used tools have had this experience. Without going into the matter further, then, we can say definitely that we cannot assure *performance* simply by buying an *analysis* of toolsteel.

Our third point was Physical Characteristics. This is a rather general term, and can include many items such as size or shape. We will eliminate these as immaterial and get down to some definite physical characteristics which have a very distinct bearing on the performance of tools. To enumerate some of them briefly, we can list microstructure, grain size, fracture grain size after hardening, hardness (Brinell, Rockwell, or file), depth of hardness penetration, and hardenability. We also find that these characteristics can be determined by tests made on the material we purchase to make the tools from, and before the tools are made. If the purchaser is quite a large user, he may wish to make these tests in his own laboratory, and select or sort the toolsteels according to his own particular requirements. If he is a small user, as are the vast majority, he will not want to go to the trouble or expense of doing this, so he will rely on the steel maker and the standards of quality and reproducibility represented by his brands. The steel maker uses these tests for physical characteristics, some of which we have just mentioned, which have become well standardized and their relation to performance determined, so the purchaser can feel reasonably sure of the quality as represented by the toolsteel makers' various brands. They represent the best insurance the average user can have. Reputable toolsteel makers are very jealous of their reputations!

This, then, leaves as our main problem the matter of selecting the correct type analysis of steel for the requirements in hand and purchasing according to the above mentioned principles.

This problem of *selection of type* must be one of the metallurgist's principal functions. It does not matter how good the steel is, or how carefully the treatment has been carried out, it will disappoint in service if the wrong type has been selected. To make this selection, the metallurgist must draw on his experience with other similar jobs and also must have set up in the shops a system of records, carefully kept and analyzed for cause and effect. Accurate records, as anyone knows who has tried, are difficult to obtain. A system to get results must be fundamentally simple and yet give necessary information. An essential part of the scheme is a sure method for marking tools to identify them at any time with the steel from which they were made.

In selecting the proper type of steel, there are certain fundamental questions which must be answered. Probably the first questions are as to function. Is the operation to be performed one of blanking, turning or cutting, forming, pressing? Is it a gage where precision and permanence are the vital factors? Are great shocks to be absorbed in its operations, or are loads light but very abrasive?

Another important point to be considered is operating temperature. Is the operation a "hot work" job, or is it carried on at normal temperatures? The operations may be similar, yet differences in operating temperatures may mean entirely different requirements in the toolsteel. Cases in point might be the cold drawing or hot extrusion of a rod through a die; in shape and form, the two dies may be quite similar, yet the type of steel used for the hot extrusion die would be of no value in the cold drawing operation, and vice versa.

Another principle to be considered in our type selection will be life requirements. In other words, two jobs may be identical in requirements, but in one case just a few pieces are to be made, and in the other the maximum long, steady runs are the rule. Obviously, the steel that will give a tool to satisfy the latter condition will also satisfy the first, yet if we use that principle in our selection, we will be guilty of metallurgical waste. It has been said that metallurgical engineering consists in putting on the job a steel which is *just* good enough.

Another very important matter to be considered is what processes must be carried out in hardening the tool. This requirement of hardening is fundamental in tools; the hardening process necessary in connection with the physical design of the tool very vitally governs our selection. The final result is often the effect of a compromise between the properties desired and the ability to weather the stresses of hardening successfully.

This, I believe, covers briefly some of the salient points to be considered in the purchase of toolsteel and shows why performance is the governing factor in its selection.

The author uses the term "metallurgical notch" to denote narrow regions within a piece of metal, or near welded joints, where considerable changes in hardness occur. These act as stress raisers and have been responsible for numerous fatigue failures

The Metallurgical Notch as a Factor in Fatigue Failure

THE STRESS RAISING EFFECT of external notches such as keyways, drilled holes, shrink fits, and the like, has received sufficient public notice to make the designer proceed with caution wherever such external geometry is encountered in a service requiring frequent reversals of stress. Furthermore, the application of welding to structural units designed to withstand dynamic loads has given the engineering profession an opportunity to observe the type of fatigue failure which occurs when the unit is used in the as-welded condition without removing the "reinforcement" or welt. It is usual for such joints to fail at the edge of the weld where the reinforcement acts as a geometric stress raiser, and the general opinion has been, therefore, that some weakness in the heat affected base metal is responsible. This is generally an erroneous conclusion, for the metallurgical structure in the heat affected zone is an improvement over that of the as-rolled base metal.

In the past year a number of fatigue failures caused by analogous metallurgical factors have come to my attention, and seem to be of sufficient interest to warrant the publication of a description of three of the examined parts.

Case No. 1 — A section of a low alloy strip steel, in the water quenched and drawn condition,

By Walter H. Bruckner
Research Asst. Prof. of Metallurgical Engineering
University of Illinois, Urbana

had been welded into a rotating structure. In service the flexure of the strip produced a maximum stress near the weld and failure, by fatigue, occurred in the strip at the metallurgical notch where the hardness had been reduced to a minimum by the heat of welding. The hardness traverse along the strip at the joint is shown below in Fig. 1.

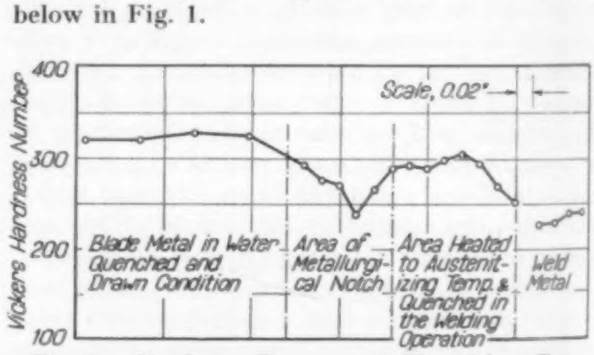


Fig. 1 — Hardness Traverse of Transition Zone Near Weld in Heat Treated Steel. Fatigue failure occurred in softened metal at metallurgical notch

Recommendations were made involving the heat treatment of the strip. It was normalized to resist spheroidization during the welding cycle and subsequent heat treatment of the assembly. The normalizing heat treatment, combined with redesign, resulted in a radical reduction in stresses near the weld and proved to be a successful solution.

Case No. 2 — A re-rolled rail steel with approximate eutectoid carbon was being used in pneumatic chisels for breaking up old concrete

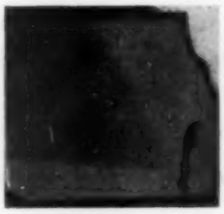


Fig. 2 — Fatigue Crack in a Concrete-Buster Chisel, Which Favors a Slightly Softened, Spheroidized Zone Between Martensitic Edge and Pearlitic Shank. Photographed natural size

paving. Long service life was the general rule for new chisels obtained from the manufacturer but after reshaping and rehardening the chisel end, failures occurred after short use. Hardening cracks were thought to be responsible but a cross section revealed typical fatigue fractures traversing a spheroidized zone just back of the hardened end, as shown in Fig. 2. Again, this was a case of a fatigue failure in the metallurgical notch where the reheating for reshaping had spheroidized and softened the lamellar pearlite in the body of the tool, which had been air cooled. The recommended heat treatment consisted of heating the entire chisel to the hardening temperature after reshaping the end. The end could thus be quenched while the shank was air cooled without forming a locally spheroidized region.

Case No. 3 — A cold rolled, planish-temper strip had been welded into a rotating structure and failure by fatigue had occurred in a region of the strip which did not exhibit any large reduction in average hardness. The strip had a low carbon content and had been fully spheroidized before cold rolling. The heating of the strip in welding had several effects, the one of major importance being to remove the extra strength obtained from cold rolling. Another effect was the tremendous increase in the ferrite grain size in regions where the carbide spheroids had started to go back into solution. The effect of the heat of welding on the re-solution of the spheroidized carbides can be seen in the sequence of Fig. 3, 4 and 5. Figure 5 was taken in a region of the strip directly under the weld and the carbides originally present in the large spheroids had been completely re-dispersed. Figures 4 and 3 were, respectively, in regions at a greater distance from the weld; the latter still shows the original comparatively massive carbide in the center of a thin pearlite field surrounded by large grains of ferrite. The usual locus of the fatigue failures was in regions similar to that reproduced in Fig. 4 where a large decrease in hardness and strength of the ferrite (due to the removal of cold work) was not fully apparent because of the local hardening in metal absorbing carbon by re-dissolving the carbides. The average change in hardness of this region was approximately 20 to 30 Vickers numbers lower than the cold rolled strip. The difference in hardness between the large grains of ferrite and the "hard spot" areas where carbides had re-dissolved must have been a large one, since the fatigue failures appeared to pass through the ferrite equi-distant from pairs of hard spots along the path of the crack.

The recommendation was to use a strip with a higher carbon content and to distribute the carbides prior to welding by a normalizing heat treatment. No cold work was done on the higher carbon strip since it was strong enough for its duty by virtue of being a higher carbon steel; likewise any strengthening induced by cold rolling would have been removed by the heat adjacent to the weld.

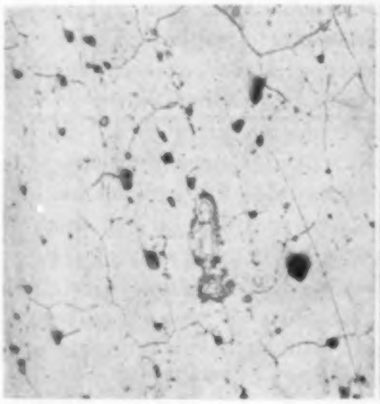


Fig. 3 — Comparatively Massive Carbides Near Weld in Cold Rolled Strip. Note grain growth and start of solution (pearlitic shell around carbide crystal). × 400

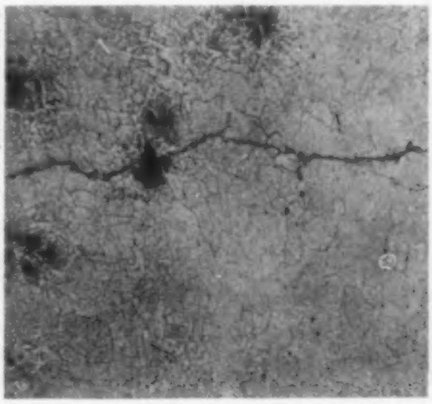


Fig. 4 — Path of Fatigue Crack Passes Through Soft Ferrite Between Hardened Zones Marking Locations of Carbide Spheroids. × 120

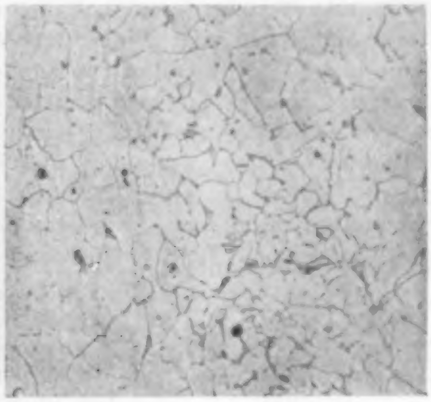


Fig. 5 — Region Directly Under Weld Where Carbides Have Been Completely Re-Dispersed. × 400. All micros nital etched

This final section of "The Progress of Metallurgy and Its Problems in Aircraft" (1943 Sauveur Memorial Lecture, Boston Chapter) considers, from a metallurgical viewpoint, the proposal that wrought and cast magnesium might be more extensively used in fighting airplanes

Wrought and Cast Magnesium for Airframes

MUCH is being said of magnesium alloys, and deservedly. Since circumstances other than purely technical often compel production engineers to make certain decisions, it might be well to remind you of the spectacular growth of the magnesium producing industry. This is plainly shown in published figures for actual production of magnesium metal beginning with pre-war year of 1940. The present surplus of metal is the result of planning over a long period by major (pre-war) producers in America, and their willingness to open their technical records and share their skilled personnel with other firms which were just entering production. By mid-1943 there were a dozen companies producing magnesium metal, with plants scattered from California to New York and from Texas to Washington.

Year	Production
1940	12,500,000 lb.
1941	33,000,000
1942	150,000,000
1943	600,000,000

By far the widest use of magnesium alloys for aircraft is in the form of castings (sand and permanent mold); next in volume is sheet and structural shapes, and finally forgings. (Editor's Note:) As of February, 1944, the monthly production by categories was as follows, according to the War Production Board:

Sand castings	6,603,000 lb.
Permanent mold castings	469,000
Die castings	221,000
Sheet, strip and plate	194,000
Extrusions	168,000
Forgings	54,000

Actual utilization of magnesium by aircraft during 1943 is impossible to estimate; it is correct to state, however, that increase in applications is mostly confined to castings and, we hope, forgings. Wider use of the latter will be predicated on the availability of necessary fabricating equipment, not available at present writing. If my information is correct our largest press is of 5000 tons capacity, as compared with 10,000 and 12,000-ton presses in production in England and Germany. Availability of this extra powerful equipment, I am told, explains the wider use of magnesium alloys in the aircraft of our allies and enemies.

Naturally, the quite limited production of forgings (and, relatively speaking, castings) in this country left many of the essential metallurgical problems unsolved. Very few foundries in 1941 had any experience with the metal. The practical way to solve production problems was to have dozens of firms, each with its own set of conditions, tackle the same general operation. Only very recently, with the backing of the Aircraft War Production Council, have we embarked upon a comprehensive, practical research program on magnesium forgings, castings and wrought products. Pioneering efforts to construct structural components of

By V. N. Krivobok
Chief Metallurgist (at the time of writing)
for Lockheed Aircraft Corp.
Burbank, Calif.

nagnesium (for example booms and wings — in few instances almost the whole airplane) uncovered many difficulties and problems of uch fundamental nature that unless they are solved the use of magnesium alloy in sheet form or structural parts is not to be expected. We may review a few of the more important ones s they appeared to an interested observer in the all of 1943.

Strong Alloys Now in Production

At present, magnesium wrought alloys are produced "as annealed" or "as hard rolled" heet. We have two main sources of supply in America, both producing alloys under their own trade names yet of comparable composition and physical properties. The designation and the specified minimum physical properties are as shown in the table above.

Alloy Name	Annealed		Hard Rolled		
	Tensile Strength	Elongation	Tensile Strength	Yield Strength	Elongation
M or AM-3S	28,000	12.0%	32,000	24,000	4.0%
F, or its close equivalent, AM-C52S	32,000	12.0	38,000	26,000	4.0
J or AM-C57S	37,000	8.0	40,000	32,000*	3.0

*Value given in U. S. Army Air Forces specification 11338; Navy Dept. specification 47 M 2 specified 28,000 psi. min., but this has been superseded in 1944 by 47 M 2a calling for 32,000 psi. min.

Comparison of mechanical properties with the same for aluminum alloys is not favorable, even if we consider the J alloy with highest physical properties. (Complete schedules for the commercial magnesium and aluminum alloys are given in *Metal Progress Data Sheets,* 1943 edition, No. 68 and 64 respectively.) Since comparative strength alone is not the only criterion for the selection of a structural material, concrete steps were taken by at least one aircraft company to utilize J or AM-C57S alloy in structural components, but these attempts had to be curtailed because of corrosion difficulties. Much work along this line is currently under way. Already strict limitation of iron and nickel "impurities" to 0.005% each has been enforced to improve the resistance to salt water. Another alloy known as AM-52S (or FS, generally regarded as equivalent to 52S), an improvement over AM-C57S from the corrosion standpoint, has been receiving some attention, especially for semi-structural parts.

In the first of this series of articles I mentioned that 60% of aircraft parts are critical in compression. Data were made available to us, which listed tensile and compressive properties for commercially produced alloy, from which the table at the bottom of the column applies to 0.064-in. sheet. While the reliability of these data, applicable to particular lot or lots of metal, is not questioned, from equally reliable sources we have been supplied with very different data which are shown in the form of stress-strain curves for the similar alloy FS, *in the same* gage and *in the same* temper. These curves are reproduced in Fig. 1 on the following page. To contemplate the significance of the point I am making, the data from the previous table show yield in tension of 40,000 psi. instead of 30,500 and yield in compression of 36,000 psi. instead of 30,000.

Obviously the careful engineer confronted with these figures, both from quite responsible sources, would note first the rather significant discrepancy in factual data for basic properties; second, a pronounced difference in the shape of the tension and compression stress-strain curves; and third, a pronounced difference in ductility of the alloy in two directions (parallel and perpendicular to the direction of rolling).

As regards this discrepancy in the data on physical properties, all of us who studied the matter concluded that the test data portray the properties of the tested pieces, and the reported difference is an *actual* difference. We further concluded that production processing either has not been standardized or the metal is very sensitive to unknown factors, which at that time had escaped notice. It was not unusual, for example, for us to find variation in mechanical properties from sheet to sheet (or even in the same sheet) of about the same magnitude.

Please remember that I am discussing the

One Series of Tests on 0.064-In. Sheet

Alloy and Temper	Direction Relative to Rolling	Yield Strength		Tension Test	
		Tension	Compression	Ultimate Strength	Elongation in 2 In.
52S-H	Perpendicular	40,000	36,000	51,000	9.0%
52S-H	Parallel	38,000	31,000	46,000	4.0

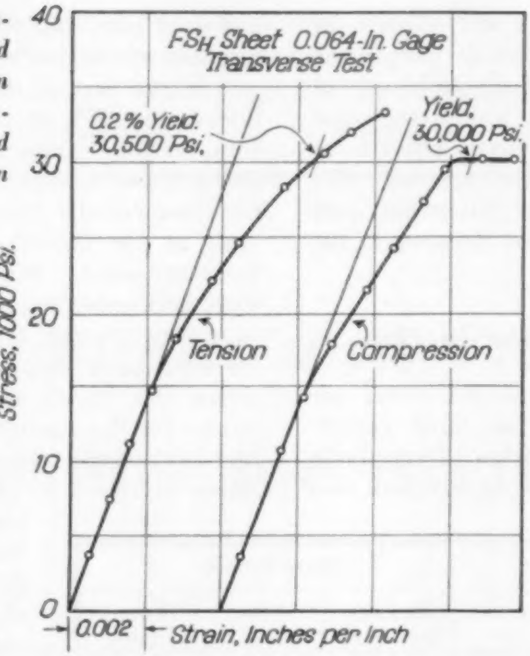


Fig. 1 — Representative Stress-Strain Curves in Tension and Compression for Magnesium Alloy FS Sheet in H Condition, 0.064-In. Gage, Tested Across the Rolling Direction

problems an airframe builder has to solve when he considers the adoption of a new alloy. They are no different from the problems the producer must also meet. Before the inherent properties of magnesium alloys can be exploited for engineering use — or *any* other family of alloys — the major metallurgical problem is to secure uniformity in basic properties. The lack of uniformity noted above, existing as of mid-1943, seriously affected the structural efficiency and necessitated, obviously, large factors of safety. The formability is also rendered difficult through inconsistency; thus the peculiarities of the stress-strain curves, together with low ductility, present distinct difficulties in cold forming operations. For example, both the 57S and the 52S alloy had to be warmed, the former by preheating to 450 and the latter to 300° F. This necessity for "hot" forming obviously introduces difficulties which, however, are by no means insurmountable if the game is worth the candle.

Stress Corrosion

Magnesium, in the popular mind, is associated with flashlight powders, and of recent years, tragically with incendiary bombs. Hence it is universally (if subconsciously) regarded as a metal with high affinity for oxygen. This impression even goes over into engineering circles; producers of magnesium have spent much time demonstrating to doubters that properly selected alloys actually do have satisfactory resistance to normal atmospheres — either in natural state or after proper protective coatings are applied.

Granted that the problem of *general* corrosion is no longer an obstacle to acceptance in many engineering structures, it nevertheless remains true that the prime obstacle to the use of the higher strength wrought magnesium alloys in primary (i.e., stressed) structures is their evident susceptibility to severe stress corrosion.

In Lockheed laboratories, tests on specimens stressed to approximately 80% of their yield strength were carried out under corrosion conditions which indeed could not be considered severe — namely, interrupted immersion in ordinary tap water (four hours in and four hours out). A summary of the results for alloy J-h (cold rolled for maximum strength) without special surface treatment is given in the table at the bottom of the column.

It is to be noted that residual stresses from cold rolling this material to the "h" condition are sufficient to cause failure. The purpose of stressing samples preheated to 400 and 600° F. was to simulate the conditions of hot forming, and to see if these elevated temperatures would relieve the residual or imposed internal stresses and thus eliminate stress-corrosion failures. Repeated tests carried out under various conditions yielded similar results — that is, ultimate failure by cracking due to stress corrosion.

When the surface was treated with recommended dichromate protective coatings, we found trouble in the 60-day test (see the table).

As far as we could determine at the time, therefore, surface treatment *retards* but *does not prevent* stress corrosion; hence, I feel safe in stating that most of the aircraft engineers, at the time of writing, did not consider surface coating

Stressed Alloy J-h in Tap Water

Method of Stressing Before Test Started	Condition After	
	30-Day Test	60-Day Test
No special surface treatment		
None (control specimen)	Failure	—
At room temperature	Broke through	—
At 400° F.	Broke ⅛ through	—
At 600° F.	Broke ⅔ through	—
Recommended dichromate protective coating		
None	No failure	Broke ½ through
Rom temperature	—	Broke ⅓ through
At 400° F.	—	Broke ⅔ through

s adequate protection. Even in the annealed ondition, the results of the laboratory stress corrosion tests are quite unsatisfactory. Actual xposure tests to industrial and sea-air atmoshere invariably resulted in ultimate failure, ometimes within an amazingly short period, ometimes only after months of exposure. This marked susceptibility to stress corrosion of the J and 57S alloys — alloys strong enough otherwise to be worthy of consideration as a material for stressed members — has created a mistrust of the stronger magnesium alloys and eliminated them as a material for primary structural parts in airframes.

However, alloys AM-52S and FS of medium strength are materially *less* susceptible to stress corrosion, while the weaker M and AM-3S alloys appear to be free from it. This is evidenced by accelerated laboratory and outdoor exposure tests. As a matter of fact, if the applied stress is approximately 75% of tension yield (or below) the failure through stress corrosion is not likely to occur with the AM-52S and the FS alloys. In itself, this circumstance is reassuring — yet it still is "taking a chance"; this circumstance, besides others perhaps more fundamental, was the reason that the Lockheed company has not considered 52S for primary structures (as of mid-1943).

[NOTE AT TIME OF PRINTING: It should be remembered that the above strictures on the use of magnesium sheets and extrusions in stressed members for airframes, due to the prevalence of stress corrosion in the really strong alloys, represent conditions as appraised in the fall of 1943. It is known that much excellent work has been and is being devoted to the problem, with hopeful expectations that it will be solved in time. It may be recalled that aluminum alloy members removed from one of our early dirigibles, apparently untouched by corrosion, had lost a great part of their ductility. A more recent appraisal of the status of magnesium is given in the following remarks by Leo B. Grant, Magnesium Sales

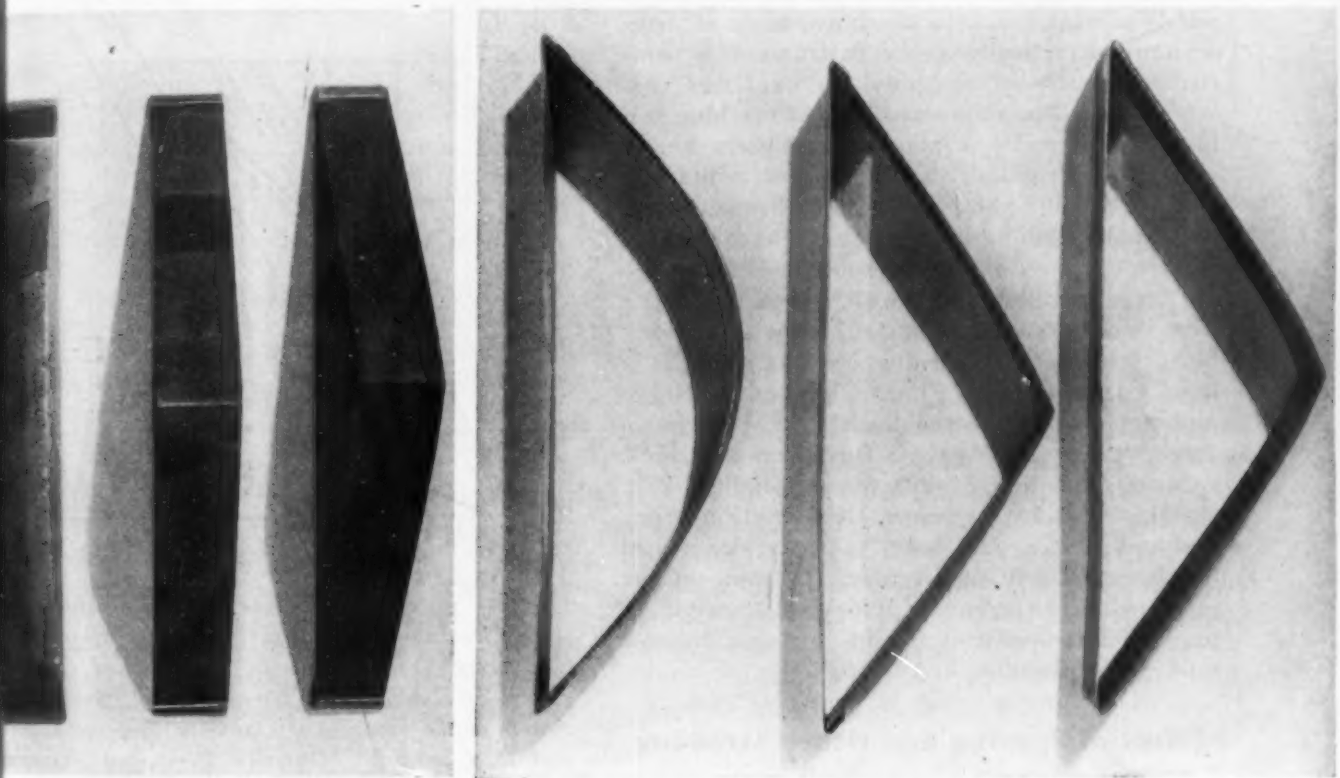


Fig. 2 and 3 — Top and Side Views of Test Pieces Showing Effect of Peening on Stress Corrosion

BOTH VIEWS, LEFT TO RIGHT:

1. Peened full length (outside surface only) after bending into arc. No failure after 30 days. This sample shows shape of others at the beginning of the test, and the method of inducing stress in outer surface of bow.

2. Peened half length (outside surface) then formed for corrosion tests. Failed in unpeened section, second day of the test.

3. Not peened. Specimens failed near the most stressed portion of the sample, after four days of exposure to test conditions.

Manager for Dow Chemical Co., before the American Chemical Society on April 4, 1944:

["Today, every bomber and fighting plane which rolls off the assembly lines of the country has, on the average, at least half a ton of magnesium in the form of castings, extrusions, forgings and sheet, all the way from the nose of the plane to its tail assembly. In the engines of bombers and fighters, whether radial or in-line, most of the main housing castings are made of magnesium. Throughout the airframe itself there are literally hundreds of parts from rudder pedals to wing brackets which are made of magnesium. Practically every instrument is constructed partly of magnesium castings and extrusions. The main structures of machine gun turrets are made of magnesium sheets and castings. Practically every type of military aircraft, from the large four-engine bombers to the small training planes, uses magnesium wheels. Magnesium is also being used now in the actual structures of the airframes, and the new Douglas cargo plane C-47 uses 2⅝ and 6-in. extruded magnesium I-beams for the floor construction. Recently, before the national meeting of the Society of Automotive Engineers, D. L. Moseley, Douglas engineer, reported that these beams were 5% lighter, 25% stronger and 35% cheaper than anything they had used before, and that a year's service record has been entirely satisfactory. In some of the more advanced combat planes, magnesium is used for ailerons, trailing edge surfaces, interior duct work, panelling and doors."]

Effect of Peening and Other Stressing

It has been observed that damage from stress corrosion originates on the *tension* side of the stressed sample; it was therefore thought advisable to investigate what effect peening or shot blasting, which effectively puts the outer layer of the metal *in compression,* may have on resistance to stress corrosion. Our results so far, which are strictly preliminary, are most interesting. Of the total number of 12 un-peened samples, all of them failed by cracking in the standard immersion test in anywhere from a few hours to four days. All peened samples remained unaffected for 30 days, when the test was discontinued. Representative views, top and side, are given in Fig. 2 and 3. Similar observations on peened samples using the accelerated test in $NaCl + K_2CrO_4$ were obtained in the laboratory of the Northrop Aircraft Corp.

A study of magnesium alloys by several investigators (Templin and Sturm; more recently Dorn and Thompsen) shows that after one or more cycles of stressing just beyond yield strength (incidentally, quite arbitrarily defined) the characteristics of aluminum and magnesium alloys are altered. The stress-strain curve for a typical magnesium alloy shows a marked reduction in yield strength both in tension and compression; in addition, the modulus of elasticity — or as it is sometimes referred to "*apparent* modulus of

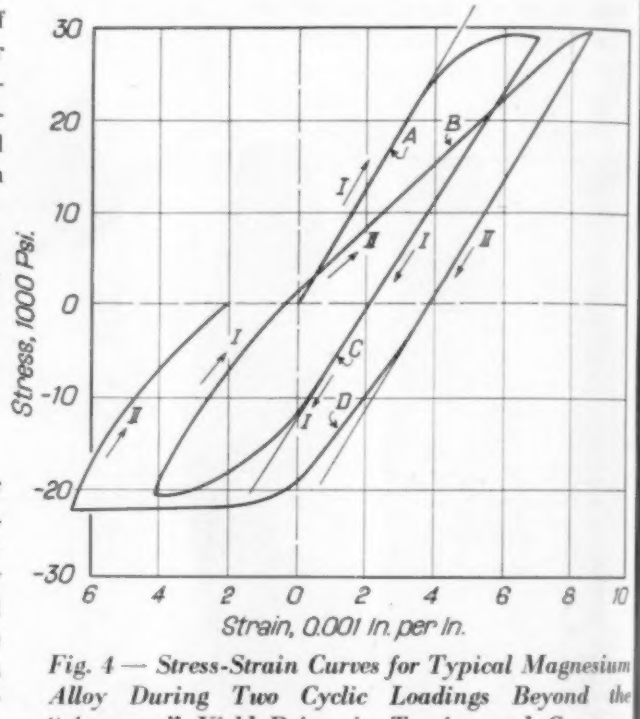


Fig. 4 — Stress-Strain Curves for Typical Magnesium Alloy During Two Cyclic Loadings Beyond the "Apparent" Yield Points in Tension and Compression — an Exhibit of the Large Effect of Plastic Deformation on the Modulus of Elasticity (Slope of Lines A and B, C and D). Courtesy Dorn and Thompsen

elasticity" — is gradually lowered. This is shown in Fig. 4. The effect of this over-stressing upholds the contention that more and immediate attention should be centered on the behavior of metals at the "high strength end" of the S-N curve. (For a clear statement of this idea, see J. O. Almen's articles in *Metal Progress,* February, May, August and September 1943).

In his book "Prevention of Failures of Metals Under Repeated Stress", H. W. Gillett calls those fractures "time fractures" which occur at stresses much higher than conventional "fatigue" stresses. Some of the German work described by him draws a conclusion that stresses corresponding to the endurance limit are safe, but that high over-stresses, although small in number, are of real importance. We had recently a vivid example of failure under these very conditions. Neither the careful stress studies, nor actual static testing

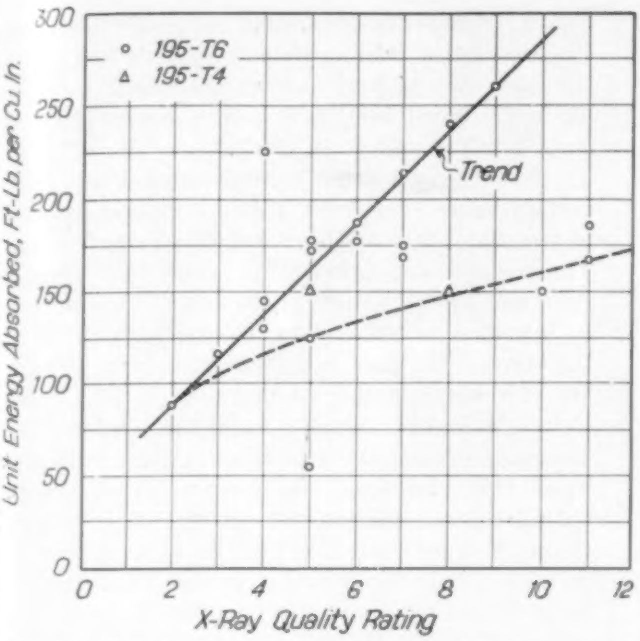


Fig. 5 — Relation Between X-Ray Quality Rating and Toughness (Unit Energy Absorbed) of Alloy 195 in Cast Form, Both After Receiving Solution Treatment (T 4) and Subsequently Aged (T 6). Courtesy B. C. Boulton

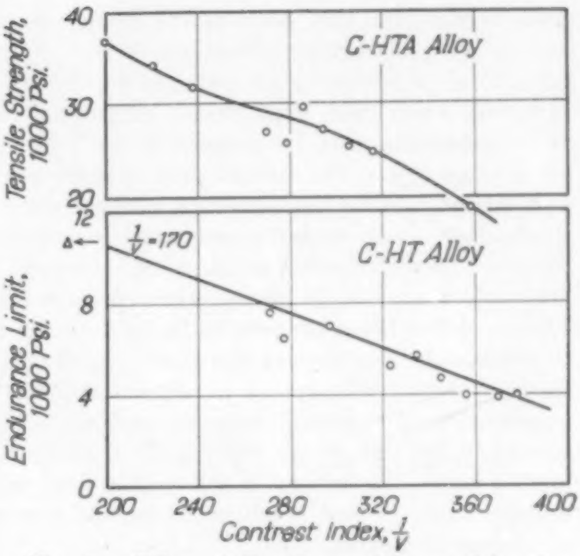


Fig. 6 — Effect of Porosity as Measured by Contrast Index on Endurance Limit (100,000,000 Reversals) of C Alloy in HT Condition, and on Its Tensile Strength in HTA Condition. (F. H. Busk)

could have predicted the results. (Despite all precautions and care it is impossible to calculate stresses to which some airplane parts may be subjected in flight; however, as F. R. Shanley points out in "Problems of Structural Research in Aircraft", 1942 Annual Meeting of the American Society of Mechanical Engineers, this problem is well in hand through the accumulation of statistical data by specially designed recorders.) The effect of occasional high stresses on *subsequent* behavior of the materials under "normal" stress conditions would be a topic of considerable importance. The metallurgical job would be to ascertain how metallurgical factors, originating in the processing or in the nature of the material, are affecting the behavior of the material under *all* conditions of stress.

Whether or not a high impact strength in any aircraft material is as important as the design of the part (or other extraneous circumstance) is debatable. Nevertheless low impact is a drawback, just as much as the low resistance to "fatigue" of magnesium casting alloys is a detriment. In an attempt to improve the latter property we resorted to the ingenious Almen's method of peening, so successful when applied to ferrous alloys. Peening or shot-blasting of aluminum alloy castings showed some encouraging results, and similar work now being carried out on magnesium castings is expected to prove beneficial. However, I believe that, fundamentally, low fatigue, notch sensitivity in impact, and limited ductility are metallurgical problems and will eventually be solved by metallurgical means.

Allow me to remind you that magnesium alloys have *not* been receiving, until recently, their share of metallurgical attention, except by two or three organizations. Magnesium sheet has not been extensively used in American aviation; so far it is a matter of sporadic individual interest. Sheet may be an interesting possibility for structural purposes *if*, through planned, applied research, certain pressing problems are solved. Otherwise, neither the over-abundance of available metal, its weight attractiveness, nor even economic considerations will expand the use of magnesium alloys as it is advertised by certain "Investment Counsel" and the like.

Castings and Forgings

As was mentioned, the use of magnesium alloys as structural material in 1943 is largely confined to castings and forgings. It was also mentioned, I believe, that such use is much more extended on the continent, in Germany, and in England. It is doubtful if British alloys are inherently better (they differ somewhat in analysis from American alloys) or that British processing technique is materially different; it might be correct to say that British technology of magnesium is more "advanced", in that the influence of each manufacturing and fabricating step is realized and controlled.

The properties of the cast material are much

influenced by the treatment *of the molten metal*, namely by properly superheating prior to pouring. (See a revealing pictorial story in *Metal Progress*, April 1942, page 491.) The actual role of superheating may be associated with factors yet undisclosed. The use of proper atmosphere in pouring, skillful conditioning and subsequent elimination of non-metallic inclusions (oxides and nitrides) formed during melting, maintenance of proper temperature to insure minimum gas solubility — all of these processing factors contribute to the best in mechanical and particularly corrosion properties. American producers realize the importance of technical control; and we in the aircraft industry are willing to follow their achievements by using more and more magnesium castings and forgings, if we are assured of technical control.

The necessity for technical control is insisted upon at all times by the aircraft users. In Lockheed's case, this insistence has been in the form of close coordination of results of inspection and foundry technique. Our investigations established a number of vital facts. One of these is that castings made at the same foundry, fulfilling aircraft orders, may be expected to be in various *degrees* of perfection, insofar as porosity, shrinkage cracks, dross, and other qualities are concerned. Furthermore, the degree of perfection is detected by *proper* X-ray technique, and second, a dependence of mechanical properties upon the amount of minute defects is indicated. The findings on which the above statement is made are reproduced in Fig. 5 and 6, by courtesy of B. C. Boulton and F. H. Busk.*

Such a correlation if established would have certain value. However, it is not always possible to translate data of this kind into actual design. The possible damaging influence of the defect is governed by the nature of the test, which in turn is intended to show how the metal will resist the stresses the part is designed to carry. Therefore, the serviceability of an actual cast or forged part will depend not only upon the kind and the "allowable amount" of imperfections, but also upon their location. *Any* defect in a critical location is not permissible, and yet the designation of a certain location as critical is not always possible. It is for this reason that the establishment of quality standards for aircraft castings is frequently most difficult.

*B. C. Boulton, "X-Ray of Aircraft Castings, Its Control and Value", Institute of Aeronautical Sciences, Annual Meeting, January, 1942; F. H. Busk, "A Correlation of Mechanical Properties and Radiographic Appearance of Magnesium Alloy Castings", A.S.T.M. Symposium on Radiography, 1943, page 128.

Processing Control

The common sense approach to this problem is the development and maintenance of processing technique for castings, thus shifting the control of the quality standards to the source of manufacturing. This development is of manifold nature; besides purely metallurgical problems of "conditioning" the metal it also includes the elimination of the major defects castings are heir to (in certain degree this is a matter of design). In all its ramifications this problem became, at some time past, quite serious. It was finally worked out for certain alloys. The results of the efforts are shown in Fig. 7, which is taken from the above mentioned paper by B. C. Boulton, which dealt with interesting details of the complex problems involved. Note that the curves, based on statistical averages, are roughly hyperbolic in form, the rejections being high for initial lots, dropping rather rapidly with subsequent lots, finally becoming asymptotic with the horizontal. This indicates that the various foundry problems, some of which are associated with the design, have been gradually solved. It is desirable to mention that the reproduced curves may not be representative of some other foundry and, certainly, would not apply, once proper control is established; the initial phase of development would not constitute *production* articles, and the *number* of castings necessary to achieve control quality may

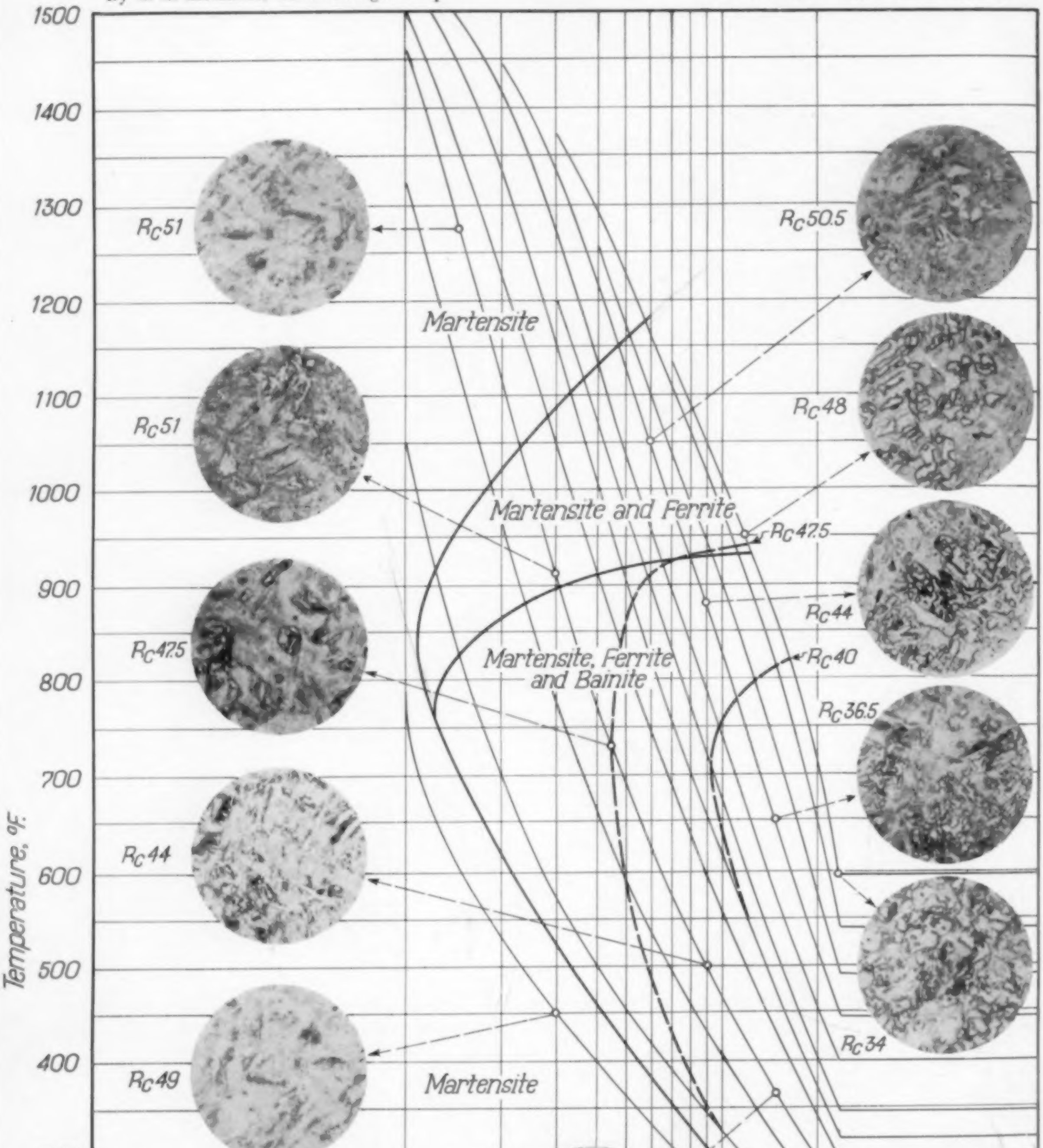
(Continued on page 1132)

Fig. 7 — Boulton's Curves Showing How Rejection Rates Dropped in a Certain Foundry as Experience in Production Was Gained

Transformation of S.A.E. 4330
During Continuous Cooling

By C. A. Liedholm, Curtiss-Wright Corp.

See *Metal Progress*, Jan. 1944, p. 94



Photomicrographs at 500 diameters

In the work on "Case Depth" published last August, eight commercial steels, gas carburized at 1600, 1650 and 1700° F., had closely similar carbon penetration gradients. The present article analyzes a similar experiment and derives accurate values of the diffusion "constant"

An Analysis of a Typical Carburizing Gradient

IN THE carburizing experiment described in *Metal Progress* for August, 1943, involving three runs at temperatures of 1600, 1650 and 1700° F. on eight commercial steels of varied analysis, it was found that the curves representing carbon concentration versus depth conformed closely to a single "Standard Gradient" curve, when suitable coordinates were employed. These coordinates were the same as those used to plot the graph of the mathematical solution for diffusion in a semi-infinite solid, when constant boundary conditions are established, and when the diffusion rate is assumed to be independent of concentration. The consistent deviation of our average experimental curves from the mathematical gradient illustrates in a qualitative manner the actual effect of carbon concentration on the diffusion coefficient. It may be remarked at this time that the carbon ranges (base carbon to surface carbon) were of about the same magnitude. Such a close check would not be found had not the carbon range been so consistent, since for a smaller range of carbon concentrations, the gradient will more nearly follow the mathematical gradient, and for a larger range, the deviation will be greater.

This report will now attempt to analyze a typical concentration-depth gradient from the viewpoint of the *range* of concentrations from surface carbon to carbon in the core, and to demonstrate quantitatively the effect of this range on the character of the gradient. A mathematical approach seems necessary, even if rather difficult, since it is necessary to understand the fundamentals before it is possible to make an intelligent application to commercial operations with gas atmospheres for carburizing, carburizing-diffusion cycles, and bright annealing. Once the fundamentals are understood, the applications are very simple.

Foreword — That no factor other than the carbon concentration has an influence on the gradient has, I think, been conclusively shown, *provided* proper boundary conditions are maintained. Hence, it may be postulated that for a given maximum and minimum %C, maintained as boundary conditions, every point on the concentration-depth curve, *when plotted on dimensionless units,* remains fixed and constant, regardless of time, actual diffusion rate, or temperature. Although no mathematical solution exists to express this fixed gradient when the diffusion rate depends directly on the concentration, the mathematical solution when *D*, the diffusion "constant", is independent of concentration, defines a rigid gradient, and values for it are known. This latter gradient will be given a special significance, since a direct comparison between this mathematical gradient with the

By F. E. Harris
Furnace Engineer
Buick Motor Division, General Motors Corp.
Flint, Mich.

actual concentration determined by a carburizing experiment will be the basis of the solution now to be attempted.

Consider the mathematical gradient, hereafter designated as the D_1 gradient, as that theoretical gradient which indicates a carbon transport, through the surface, equivalent to that obtained by the actual gradient under study (which, for brevity, will be named D_c gradient). The significance of the subscript "1" is of course to indicate the constancy of D, while the "c" subscript for the actual gradient signifies the dependency of D on concentration.

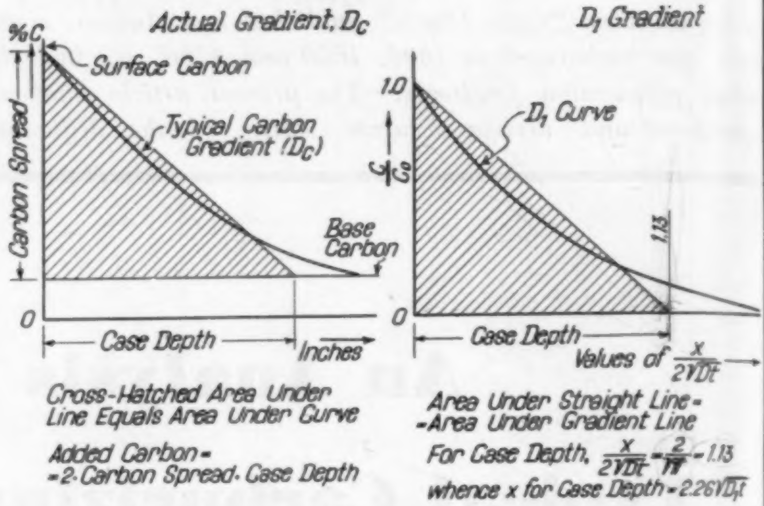


Fig. 1 — Diagrammatic Expression of Actual and Hypothetical Carbon Gradients, D_c and D_1 Respectively. For derivation see Metal Progress, August 1943, page 265

The diagrammatic expression is shown in Fig. 1. Reference to the preceding article in *Metal Progress* will refresh the reader's mind on the derivation, and from the relationships noted we may immediately write the following equations:

Added Carbon = 2 · Carbon Spread · Case Depth (Equation 1)*

Added Carbon = $4.52\sqrt{D_1 t}$ · Carbon Spread (Equation 2)

Solving this second equation for D_1, whose dimensions are inches ²/hr., we have

$$D_1 = \left(\frac{\text{Added Carbon}}{\text{Carbon Spread}}\right)^2 \div 20.4\, t \qquad (3)$$

Where D_1 = hypothetical diffusion constant, in inches ²/hr., assumed to be independent of carbon concentration,

Added Carbon = pounds of carbon through 10 sq.ft. of surface area,

Carbon Spread = max. carbon % — min. carbon %,

and t = time in hours.

Basis of Solution — As was pointed out at the beginning of the foreword, the D_c gradient, plotted on suitable coordinates, is fixed for a given range of carbon concentrations.

*This equation may be more easily understood by reference to the article on "Case Depth", *Metal Progress*, August 1943, page 270. The area under the carbon penetration curves in Fig. 1 is proportional to the carbon introduced to the steel during carburizing, and the area of the cross-hatched triangle is obviously ½ (Carbon Spread) (Case Depth). If this area is multiplied by four it will express the amount of carbon in pounds added to 10 sq.ft. of surface area, which is the definition for "Added Carbon". Hence

Added Carbon = 2 · Carbon Spread · Case Depth

The hypothetical gradient, D_1, is prescribed by an equation which may be written

$$\frac{C}{C_0} = 1 - \phi\left(\frac{x}{2\sqrt{Dt}}\right) \qquad (3a)$$

where ϕ is the probability integral, C is the gain in carbon at any given point x below the surface, and C_0 is the *gain* in carbon at the surface.

Boundary conditions are:

$C = C_0$ *at* $x = 0$ for all times t
$C = 0$ at $x > 0$ and $t = 0$
$C = C_{x,t}$ at $x > 0$ and $t > 0$

Derived values of this curve, pertinent to the solution, are given in Table I and graphed in Fig. 5.

The specified boundary conditions hold concisely, also, for the D_c gradient. Both of these gradients exemplify in every particular and to the same degree the condition of an *unsteady* state, that is, conditions existing in any system prior to the time when equilibrium has been reached. Yet the absolute relationship proven by experiment to exist between the two gradients (for a specific value of carbon concentrations for D_c) indicates that a relative solution for D_c may be obtained by assuming a hypothetical *steady* state. Two conditions must be kept in mind:

(a) The steady state concept has significance merely in connection with the solution and has no basis in fact. The qualifying condition used in changing the unsteady state form to the steady state concept is allowable only to express a relative difference between the two gradients.

(b) The numbers and expressions used in connection with the two gradients have of themselves no precise significance. However, these

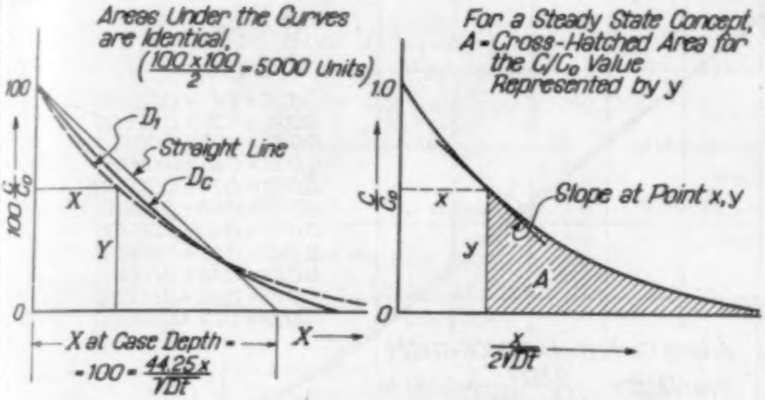


Fig. 2 — Carbon Gradients for Assumed Steady State. In the left hand sketch $X=100$ at $x/2\sqrt{Dt}=1.13$

expressions are applied to each gradient in exactly the same ratio and in the same manner. This solution, at this point, is concerned merely with the *relative* value of D_c at every %C represented on the gradient, compared to a D_1 of unity.

Analysis for Steady State

We will now consider a gradient constructed with the proper coordinates and analyze this gradient as though a steady state existed. By *steady state, D* is defined as the ratio of the total mass of solute per unit time which flows across any small section to the rate of decrease of the concentration per unit distance.

Imagine the ordinate at the point x, y (Fig. 2, above, at right) as representing the trace of a vertical plane standing at right angles to the sheet. This ordinate, then, will represent an area, with no thickness in the x direction.* The shaded region below the graph to the right of the ordinate in the $+x$ direction represents, diagrammatically, added carbon, and is represented by the symbol A. Since the value of the ordinate, $\frac{C}{C_0}$, represents an area, then $\frac{A}{C/C_0}$ represents the amount of solute per unit area passing through a hypothetical surface.

Now $\frac{d\frac{C}{C_0}}{dx}$ $\left(\text{or } \frac{dy}{dx}\right)$ represents the concentration gradient at point x,y, and the amount of solute passing is equal to this gradient multiplied by the diffusion constant* and the time — that is to say to the expression $Dt\ \frac{dy}{dx}$.

These two expressions for the same thing lead to the equation

$$\frac{A}{C/C_0} = Dt\ \frac{dy}{dx} \text{ for steady state} \qquad \text{(Equation 4)}$$

where D = diffusion coefficient and t is the time unit. This is the equation familiar to physicists for defining D_1 in connection with the *steady* state.

Now, with freedom from significant numerical values, we may, for the *unsteady* state, consider A as "added carbon" and $\frac{C}{C_0}$ as "carbon spread".

Then from equation (2) we may write for the unsteady state gradients, D_c and D_1

$$\frac{A}{C/C_0} = \sqrt{Dt}, \text{ unsteady state} \qquad (5)$$

(In the above paragraph, "freedom from significant values" means that any proportionality factor or numerical coefficient will be the same for D_1 and D_c, thus cancelling out in the final

*The graphs in this article show linear diffusion. Actual examples for added carbon assume an *area,* which on the graph is shown as a line.

*Diffusion constant or diffusivity coefficient is defined as the mass of a substance diffusing in unit time across a unit area through a unit concentration gradient.

Table I — Properties of Theoretical Concentration-Depth Curve (D_1)

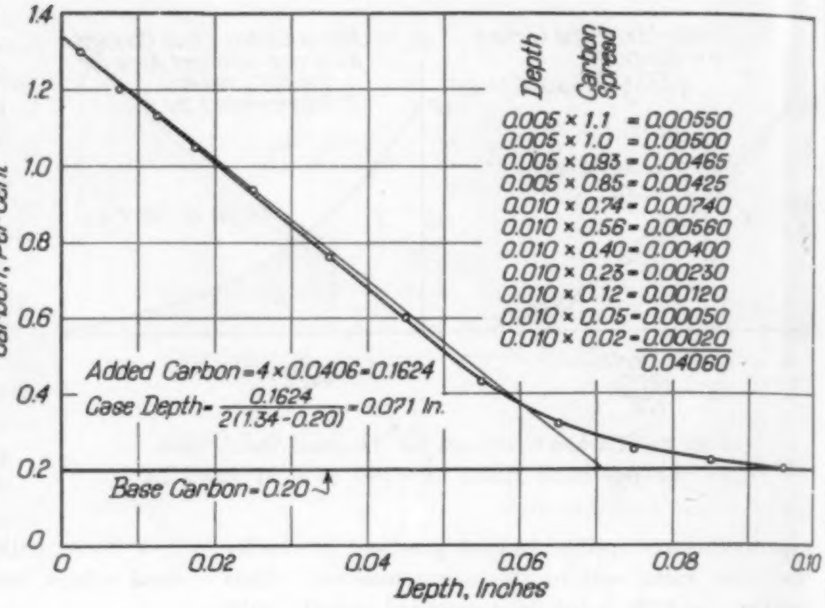
Plotted on coordinates $Y = 100\frac{C}{C_0}$, $X = 100$ at $\frac{x}{2\sqrt{Dt}} = 1.13$

Total area under curve = 5000

A_1 = area to right of ordinate for a given C/C_0 value

$\frac{A_1}{C/C_0}$	Slope	$\frac{A_1}{C/C_0}$	Slope	$\frac{A_1}{C/C_0}$	Slope	$\frac{A_1}{C/C_0}$	Slope
5000	1.2732	3690	0.9916	3540	0.9162	3390	0.8222
4500	1.2383	3680	0.9869	3530	0.9109	3380	0.8263
4000	1.1178	3670	0.9821	3520	0.9055	3370	0.8204
3900	1.0815	3660	0.9773	3510	0.9001	3360	0.8144
3800	1.0410	3650	0.9724	3500	0.8946	3350	0.8085
3790	1.0367	3640	0.9675	3490	0.8891	3340	0.8025
3780	1.0324	3630	0.9626	3480	0.8835	3330	0.7964
3770	1.0280	3620	0.9576	3470	0.8779	3320	0.7903
3760	1.0236	3610	0.9526	3460	0.8723	3310	0.7842
3750	1.0192	3600	0.9475	3450	0.8667	3300	0.7780
3740	1.0147	3590	0.9424	3440	0.8610	3290	0.7718
3730	1.0102	3580	0.9372	3430	0.8553	3280	0.7655
3720	1.0056	3570	0.9320	3420	0.8496	3270	0.7592
3710	1.0010	3560	0.9268	3410	0.8438	3260	0.7529
3700	0.9963	3550	0.9215	3400	0.8380	3250	0.7466

Fig. 3 — Experimental Data for a Carburized S.A.E. 1020 Steel Bar, Used to Compute the Diffusion Rates



equation. It also allows us to use the equality sign rather than the ratio sign.)

Our problem of comparing the experimental and the hypothetical value of the diffusion constant requires that we reconcile the left hand terms of equations (4) and (5), representing the steady state and the unsteady state respectively. Since we desire to express our solution equation in the form of equation (4), such that any point on the gradient may be investigated, we must modify the $\frac{A}{C/C_0}$ factor by dividing by $\sqrt{Dt}$ and write★

$$\frac{A}{\frac{C}{C_0}\sqrt{Dt}} = Dt\,\frac{dy}{dx} \qquad (6)$$

D is a variable for the D_c gradient; t may be taken as unity, so we simplify equation (6) into

$$\frac{A}{C/C_0} = D^{3/2}\,\frac{dy}{dx} \qquad (7)$$

We now apply equation (7) to both the D_1 and D_c gradients. Since we merely desire *relative* values, taking D_1 as unity, we write equation (8):

$$\frac{A_1}{C/C_0} = \frac{dy}{dx}, \text{ for } D_1 \text{ gradient (Relative } D_1 = 1)$$

and for D_c relative to D_1

$$\frac{A_c}{C/C_0} = (\text{Relative } D_c)^{3/2}\,\frac{dy}{dx} \qquad (9)$$

In equation (8) the significance of $\frac{dy}{dx}$ may be taken as the slope of the D_1 gradient, at the point under consideration. Furthermore an analysis of the Probability Integral Table discloses that for every value of $\frac{A}{C/C_0}$, there exists

★When the Editor told the author that he (the Editor) bogged down here, Mr. Harris forwarded the following justification of this step in the analysis:

Carburizing is symbolized by the semi-infinite solid. Fixed concentration is maintained at the surface; a constant base concentration is held at distant points from the surface. This point continually changes, together with every point on the gradient, except at the surface. The rate of flow through the surface is constantly diminishing as time elapses.

Carburizing follows exactly Fick's Law. Considering linear diffusion we could write equation (3a) for the gradient if D were independent of concentration. Actually every point on the gradient, except the surface, is continually affected by the concentration represented by that point, since D is dependent on concentration and increases with it. For given constant values of concentrations, from base to surface, this deviation is fixed for the gradient which may be drawn with coordinates common to the D_1 gradient.

Now, let us choose one temperature, and a time of unity. Then for a given experiment,

$$D \propto \left(\frac{\text{Added Carbon}}{\text{Carbon Spread}}\right)^2$$

This expression is true for both D_1 and D_c gradients, since the total areas under the two gradients are equal.

For linear diffusion as shown on the graph, added carbon by the proper proportionality factor may be area under the gradient. The carbon spread is proportional to the C/C_0 ordinate, and at the surface, $x = 0$ for total carbon added; we may write for both D_1 and D_c

$$D \propto \left(\frac{A}{C/C_0}\right)^2$$

$$\text{or} \quad \frac{A}{C/C_0} \propto \sqrt{D}$$

This is written for the total solute passing through the steel surface. Since each point on both the D_1 and D_c gradient is fixed (D_c describes a set gradient for a given range of carbon concentrations), we will now try to compare each point on the D_c gradient by some method with the D_1 gradient, whose values are known. Since the gradients are invariant, the steady state equation is suggested and we write

$$\frac{A}{C/C_0} = D\,\frac{dc}{dx} = D\,\frac{dy}{dx}$$

where A is the area under the curve beyond the point x, y.

This is entirely hypothetical for the carburizing process as has been developed, since A is not steady but is really proportional to $\sqrt{D}$ (for both D_1 and D_c). Hence we correct the $\frac{A}{C/C_0}$ value of the steady state, namely $D\frac{dy}{dx}$, by multiplying by $\sqrt{D}$, and, merely for the purpose of comparing D_1 and D_c, write

$$\frac{A}{C/C_0} = D^{3/2}\,\frac{dy}{dx}$$

a definite and distinct value of the slope. These matched values are tabulated in Table I, and are the key to the solution. For a given slope value for a point on the D_c gradient, the value of $\frac{A}{C/C_0}$ for D_1 is taken from Table I. The value of $\frac{A}{C/C_0}$ is then obtained graphically at any point under examination from the experimental gradient being analyzed, and the solution is written

$$\text{Relative } D_c)^{3/2} = \frac{\frac{A_c}{C/C_0} \text{ for the actual } D_c \text{ gradient}}{\frac{A_1}{C/C_0} \text{ for the hypothetical } D_1 \text{ gradient}}$$

which is equation (10), an expression that is derived from equation (9) by substituting the value of $\frac{dy}{dx}$ given in equation (8).

The choice of the units employed is immaterial to the solution, except of course, that the same scale of coordinates is applied to both gradients. Coordinates chosen arbitrarily are:

$$Y = 100\frac{C}{C_0}\ ;\quad X = 100 \text{ at "case depth"}$$

$$A \text{ (where } \frac{C}{C_0} = 1) = \frac{(100 \cdot 100)}{2} = 5000$$

Slope of straight line connecting $X = 0$, $Y = 100$ and $X = 100$, $Y = 0$ is 1.000.

These graphs are shown at the left of Fig. 2 and all tabulations and solutions will be derived from these coordinates.

Analysis of an Experiment

A carburized test bar of S.A.E. 1020 steel was used for applying this theoretical solution. The total carburizing time was 8 hr., and the bar was water quenched within 1 sec. of removing from the carburizing atmosphere, to prevent loss of surface carbon. The temperature of carburization was 1700° F. Analyses of successive layers are shown in Fig. 3, which shows that the added carbon is 0.1624, while the carbon spread (1.34% C − 0.20% C) is 1.14, giving a case depth of 0.071 in.

The results of the chemical determinations are shown graphically in Fig. 3. Analysis of the curve is done arithmetically according to the above principles, and the data are tabulated in

Table II — Analysis of Carburizing Experiment; S.A.E. 1020

Col. I	Col. II	Col. III	Col. IV	Col. V	Col. VI	Col. VII	Col. VIII	D_c Actual (Note *f*)	
$100\frac{C}{C_0}$ or Y	% C (Carbon Analysis)	A_c (Note *a*)	$\frac{A_c}{C/C_0}$ (Note *b*)	Slope (Note *c*)	$\frac{A_1}{C/C_0}$ (Note *d*)	(Relative D_c)$^{3/2}$ (Note *e*)	Relative D_c	Col. IX $D \cdot 10^4$ In²/Hr.	Col. X $D \cdot 10^7$ Cm²/Sec.
100	1.34	5000	5000	1.031	3776	1.323	1.205	1.49	2.67
95	1.28	4526	4764	1.031	3776	1.261	1.167	1.44	2.58
90	1.23	4077	4530	1.031	3776	1.199	1.128	1.40	2.50
85	1.17	3652	4296	1.031	3776	1.137	1.089	1.35	2.42
80	1.11	3252	4065	1.031	3776	1.076	1.050	1.30	2.33
75	1.06	2876	3835	1.031	3776	1.015	1.010	1.25	2.23
70	1.00	2523	3604	1.031	3776	0.9544	0.9694	1.20	2.15
65	0.94	2196	3378	1.031	3776	0.8948	0.9286	1.15	2.06
60	0.88	1893	3155	1.031	3776	0.8355	0.8873	1.10	1.97
55	0.83	1614	2934	1.031	3776	0.7770	0.8452	1.05	1.88
50	0.77	1359	2718	1.031	3776	0.7197	0.8021	0.99	1.78
45	0.71	1128	2507	1.031	3776	0.6639	0.7610	0.94	1.67
40	0.66	922	2305	1.031	3776	0.6104	0.7196	0.89	1.59
35	0.60	740	2114	1.031	3776	0.5598	0.6791	0.84	1.50
30	0.54	582	1940	1.031	3776	0.5137	0.6414	0.79	1.41
25	0.48	449	1796	1.031	3776	0.4756	0.6093	0.75	1.34
20	0.43	321	1605	0.871	3458	0.4641	0.5994	0.74	1.32
15	0.37	210	1400	0.737	3235	0.4327	0.5721	0.71	1.27

Note *(a)*; A_c is area under actual carburizing curve (Fig. 3 or 6) to right of ordinate on basis of entire area = 5000 units.

Note *(b)*; $\frac{C}{C_0} = \frac{\%\text{ Carbon} - \text{Base Carbon}}{\text{Surface }\%\text{ Carbon} - \text{Base Carbon}} = \frac{\%\text{ C} - 0.20}{1.34 - 0.20}$

Note *(c)*; Slope = dY/dX for the carburizing curve (Fig. 6) on the scale for which $Y = 100\ C/C_0$ and X = % Case Depth.

Note *(d)*; Figures taken from Table I for theoretical concentration-depth curve, to match values of slope in column V.

Note *(e)*; Divide items in column IV with items in column VI. See text, equation (10).

Note *(f)*; Values in column IX are had by multiplying Relative D_c (column VIII) by 1.24. See text. Conversion factor for column X is 1.791 x 10^{-3}.

Table II. Actual %C in column II is figured for various values of $100 \frac{C}{C_0}$ by pro-rating the difference between surface carbon.

For computing the areas under the curves beyond the respective ordinates it will be more convenient to plot the concentration-depth curve as in Fig. 6, where the carbon spread (1.14) is divided into 100 units, and the "case depth" (0.071) is also divided into 100 units. The total area under the curve can then be measured by planimeter, or figured by dividing it into elementary areas 5 units wide and scaling the average height. This total area is then multiplied by a factor to bring it to 5000 units. Similarly the area beyond the ordinate where $Y = 95$ is computed and multiplied by the same factor. This gives A_e for $Y = 95$, and so on for all values in column III of Table II.

Column IV is readily computed from figures in columns I and III. Column V, showing slope, is easiest computed by drawing tangents to the curve at the various ordinates, measuring their angles with the horizontal with a protractor, and

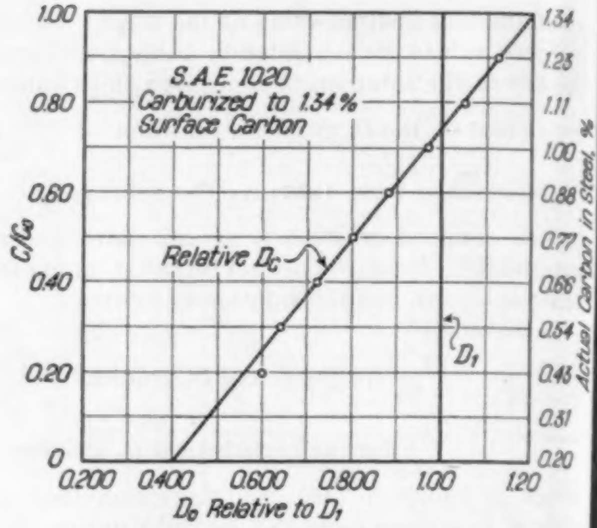


Fig. 4 — Relative D_c Plotted Against C/C_o for Carburized Sample of S.A.E. 1020. Data from Table II, columns I and VIII

taking out the tangent of these angles from a table of natural trigonometric functions. The experimental curve we are analyzing is practically a straight line from $Y = 100$ to $Y = 25$; hence the table shows a constant slope for this distance.

Column VI contains $\frac{A_1}{C/C_0}$ figures for the theoretical concentration-depth curves, taken out of Table I by interpolation for values of slope shown in column V. Items in column VII are had by dividing items in column IV with items in column VI, according to equation (10) above, and column VIII is then easily computed.

Figure 4 shows how Relative D_c (column VIII) varies with C/C_0, and it will be observed that $D_c = D_1 = 1.00$ at $C/C_0 = 0.75$ (approx.). It should be emphasized that these values, when represented in dimensionless units, are true only for the carbon range found in this particular carburizing test, namely 1.34 to 0.20% carbon.

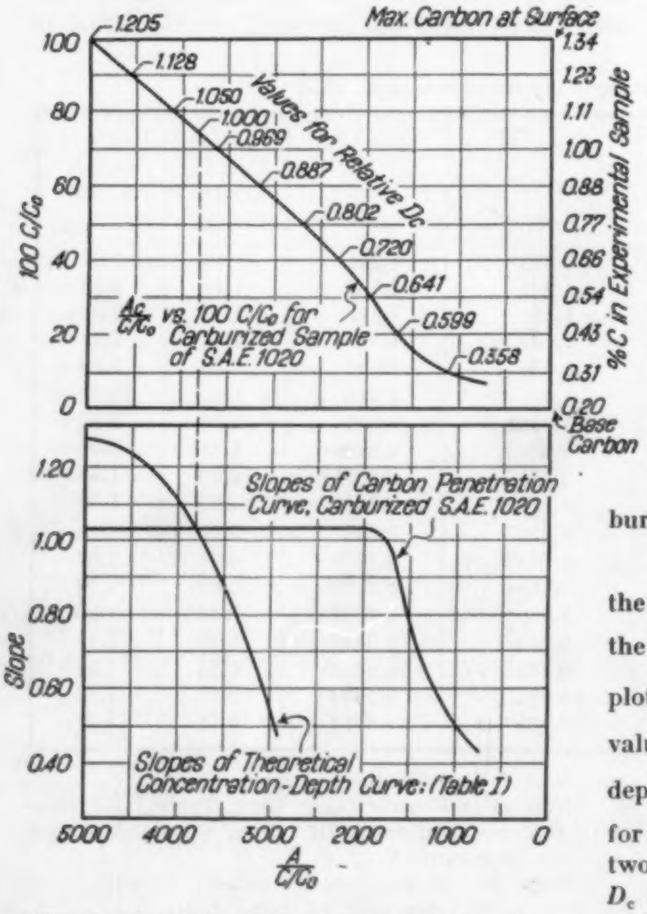


Fig. 5 — Dual Plot Showing That Slopes of Theoretical and Experimental Concentration-Depth Curves Are Equal at 100 C/C_o = 75

A dual plot is also given in Fig. 5, which shows the $\frac{A_e}{C/C_0}$ values versus $100 \frac{C}{C_0}$ (and actual %C) for the carburized sample. In the lower part of Fig. 5 are plotted the relationships between slopes and $\frac{A_1}{C/C_0}$ values in Table I for the theoretical concentration-depth curve, and slopes and $\frac{A_e}{C/C_0}$ values in Table II for the experimental curve. The intersection of these two curves at $100\ C/C_0 = 0.75$ marks the place where D_c and D_1 values are equal. This checks the result shown in Fig. 4.

We will now derive the actual diffusion coefficients, from the test specimen in question. Equation

(3) which expresses the coefficient for D_1 will be repeated:

$$D_1 \text{ (in inches}^2\text{/hr.)} = \left(\frac{\text{Added Carbon}}{\text{Carbon Spread}}\right)^2 \div 20.4\, t$$

We have values for the quantities on the left side, taken from the carburizing experiment:

Added Carbon = 0.1624
Carbon Spread = (1.34 − 0.20) = 1.14
t = 8 hr.

Solving,

$$D_1 = 1.24 \times 10^{-4} \text{ in.}^2 \text{ per hr.}$$

But from Fig. 5 we know that $D_1 = D_c$ at a value of 0.75 for C/C_0, corresponding to an actual carbon analysis of 1.06% in the carburized test bar. Therefore we are justified in writing

$$D_{(c=1.06)} = 1.24 \times 10^{-4} \text{ in.}^2\text{/hr.}$$

and this approximate value will be found in Table II, column IX, in the line corresponding to $C/C_0 = 0.75$ and actual %C = 1.06.

Multiplying Relative D_c values by 1.24×10^{-4}, we tabulate in column IX directly the actual D_c values for the particular %C involved.

From this tabulation, derived at 1700° F., with a carbon concentration range of 1.34% to 0.20%, the gradient analysis is completed by comparing these derived values of D_c with those obtained by Wells and Mehl. Since their values are expressed in cm.²/sec. the conversion factor is expressed as

$$\text{cm.}^2\text{/sec.} = 1.791 \times 10^{-3}\ \overline{\text{inches}^2}\text{/hr.}$$

and we compare the derived diffusion constants:

Carbon Concentration	Harris; 1020 Bar at 1700° F.	Wells and Mehl; Diffusion at 925° C. (1697° F.)
1.00%	2.15×10^{-7} cm.²sec./sec.	2.1×10^{-7} cm.²/sec.
0.70	1.66×10^{-7}	1.6×10^{-7}

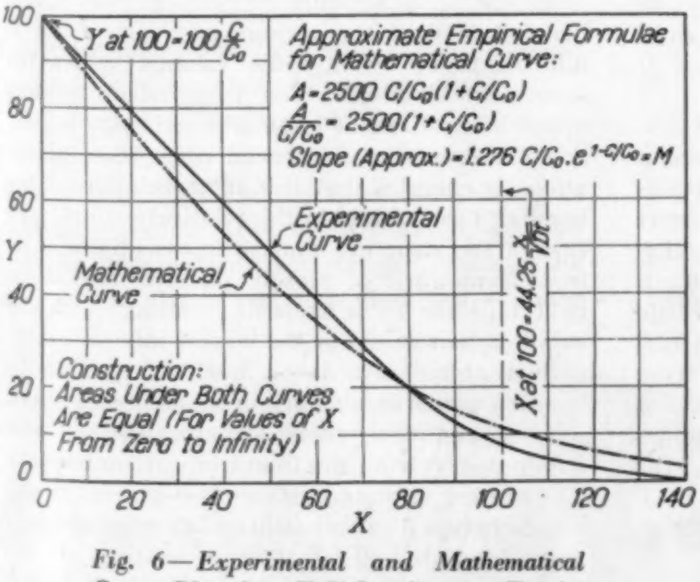


Fig. 6—Experimental and Mathematical Curves Plotted on X,Y Coordinates. Empirical formulae are good only for rough checks

Structure of Cementite*

N. J. Petch has done some valuable work at Cambridge University on the atomic structure of constituents in steel, and the results have been published in the *Journal* of the Iron and Steel Institute. The latest on cementite may be reviewed in connection with two other contributions.* The work largely has to do with the location of the carbon atoms, since the position of the iron atoms had already been fixed with considerable accuracy.

In austenite the carbon atoms are almost certainly located at the centers of the unit cubes, and are thus surrounded by six iron atoms arranged as corners of an octahedron (see *Metal Progress*, July 1942, page 120). The iron atoms in martensite assume a body-centered tetragonal lattice, with axial ratio of only 1.03, so the structure is very nearly cubic. If it is accepted that, after the formation of martensite, the martensite (110) plane and [111] direction are parallel to the (111) and [110] direction of the parent austenite, the most probable positions of the carbon atoms are at the centers of the square faces of the unit of the body-centered tetragonal cell. (*Metal Progress*, May 1943, page 762.)

Since cementite forms from martensite at a much lower temperature than from austenite, Hume-Rothery and his associates in the second paper mentioned in the footnote believe there must be some transition from martensite to cementite that involves comparatively small atomic movements. The diagrams on page 1118 show the suggested mechanism.

Figure 1 shows six unit cells of a body-centered martensitic structure, and the carbon atoms are to be thought of as occupying the centers of square faces such as *aikc* and *ckme*. If, now, a simple shear takes place in the central layer of cells, in such a way that the top and bottom

*"The Crystal Structure of Cementite", by H. Lipson and N. J. Petch, *Journal* of the Iron and Steel Institute, Vol. 142, Part II, 1940, p. 95p.

"The Lattice Spacings and Crystal Structure of Cementite", by Wm. Hume-Rothery, G. V. Raynor, and A. T. Little, *Journal* of the Iron and Steel Institute, Vol. 145, Part I, 1942, p. 143p.

"The Interpretation of the Crystal Structure of Cementite", by N. J. Petch, Advance Copy, Paper for Spring 1944 meeting, Iron and Steel Institute, London.

layers are displaced relatively to each other in the [100] direction by an amount of the order of ½ *a*, where *a* is the length of a side of a unit cell, the stage shown in Fig. 2 is reached. This structure contains several features which show similarity with the structure of cementite as regards the general atomic configuration, and may be regarded as a distorted form of the latter. Comparatively minor adjustments of angles and distances enable the exact cementite structure to be formed (Fig. 3). The essential changes in this final adjustment are:

(a) The carbon atoms take up positions which are alternately a little outside or inside the planes of faces such as *aikc* and *ckme*. Carbon atoms should be placed outside planes *aikc*, *emog*, *jrtl* and *nvxp*, and inside planes *ckme* and *ltvn*. This displacement of carbon atoms allows the faces concerned to contract so that, for instance, the distances *ai* and *ac* shorten while the face remains approximately square. This leads to an expansion of dimensions such as *bj* and *iq*, while the angle between the planes which were the vertical faces of the parent cells is no longer a right angle, but greater. Distances such as *ab* also contract.

(b) At the same time the distance of the central atoms, in the sheared middle section of the structure, from corners such as *c* and *k*, or *n* and *v*, increases in such a way that these atoms like *C* and *D* lie either vertically below the central atom of the unit above or vertically above the central atom of the unit below; thus, atom *C* falls vertically below atom *A*, and atom *D* vertically above atom *F*.

(c) It must also be assumed that the distances *iA*, *aA*, *bC* and *cC* also increase from a value close to that characteristic of the body-centered cube (approximately 2.48 Å for α-iron) to the value of 2.68 Å characteristic of cementite.

Two precise measurements of the unit cell were made, one by Hume-Rothery from cementite extracted electrolytically from 1.07% carbon tool-steel, and the other by Lipson and Petch from cementite synthesized by passing CO over hot Fe_2O_3. (Differences between these two determinations are considerably greater than 0.0005±, the probable error.)

Parameter	From Steel	Synthetic
a	4.5155	4.5144
b	5.0773	5.0787
c	6.7265	6.7297

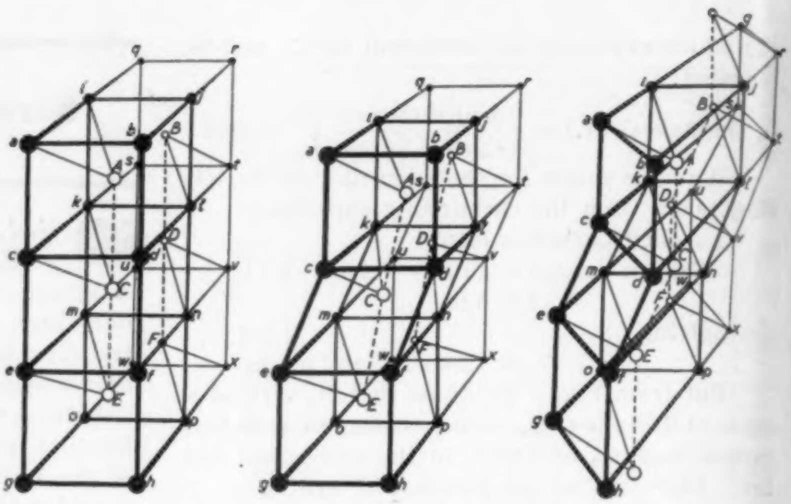


Fig. 1 (Left) — Body-Centered Cubic Martensite; Fig. 2 (Center) — Shear Displacement of Half Length of Cube Side; Fig. 3 (Right) — Final Adjustment to Cementite Structure. Only the positions of iron atoms are shown. Atoms at the corners of cubes are noted by full circles, whose size diminishes as the atoms recede. Atoms at centers of cubes are noted by open circles

Variable Carbon in Cementite

In the latest contribution mentioned in the footnote on page 1117, Petch suggests that the cementite cell can vary somewhat in dimension because it is not necessarily constant in iron-to-carbon ratio, as implied by the conventional formula Fe_3C. He arrives at this hypothesis after considering the type of bonds between atoms in the cementite crystal. Since each iron atom has 11 or 12 practically equidistant iron neighbors, the bond between them must be "metallic" in nature rather than chemical ("electrovalent" or "covalent"). Likewise, since each carbon atom has six practically equidistant iron neighbors situated at the corners of a prism, "it is difficult to see what ionic valency values the atoms would adopt. The iron-carbon bonding appears also to be of a metallic nature.

"In cementite the actual disposition of the atoms is complex, but this interpretation of the bonding forces leads to the relatively simple picture of the structure consisting essentially of an iron framework of closely packed iron atoms held together by a metallic bonding, with the small carbon atoms in the largest interstices, the carbon atoms also being held in position by bonding which has a certain amount of metallic nature, and the whole structure being more dominated by iron-iron than iron-carbon bonding. The present view suggests a close general resemblance between the structure of ferrite, austenite and cementite, all of them consisting of iron frameworks in the interstices of which carbon atoms are accommodated; *(Continued on p. 1128)*

Personals

Walther Mathesius, president of Geneva Steel Co., Utah subsidiary of U. S. Steel Corp., and past national trustee ⊕, is the first recipient of the Francis J. Clamer Medal for Meritorious Achievement in the Field of Metallurgy, awarded by the Franklin Institute in Philadelphia for his outstanding contributions in converting the art of blast furnace operation to a science.

Honored by the American Institute of Chemists: Willard Henry Dow, president, the Dow Chemical Co., awarded the Gold Medal.

Willis R. Whitney ⊕, honorary vice-president of the General Electric Co., has been made an honorary member of the Electrochemical Society.

Promotions by Crucible Steel Co. of America: W. G. Hassel, to manager of sales, Pittsburgh Crucible Division; W. W. Noble ⊕, to succeed Mr. Hassel as manager of the Detroit Branch; John S. Billingsley ⊕, to succeed Mr. Noble as manager of the Pittsburgh Branch; and Leo J. Rohrer, to succeed Mr. Billingsley as acting manager of the Order and Scheduling Department in the New York executive offices.

A. R. Stevenson ⊕, formerly metallurgical representative, Carnegie-Illinois Steel Corp., Chicago district, is now with Tube Turns, Inc., Louisville, Ky., in the metallurgical department.

Russell H. Lauderdale ⊕, formerly research engineer at Battelle Memorial Institute, Columbus, Ohio, has become chief metallurgist of the Northern Ordnance Co., Inc., Minneapolis.

C. O. Ballou ⊕, formerly in charge of engineering and development on the caliber 30 steel cartridge case at the Denver Ordnance Plant, has accepted an engineering position with the Clinton Engineering Works, Knoxville, Tenn.

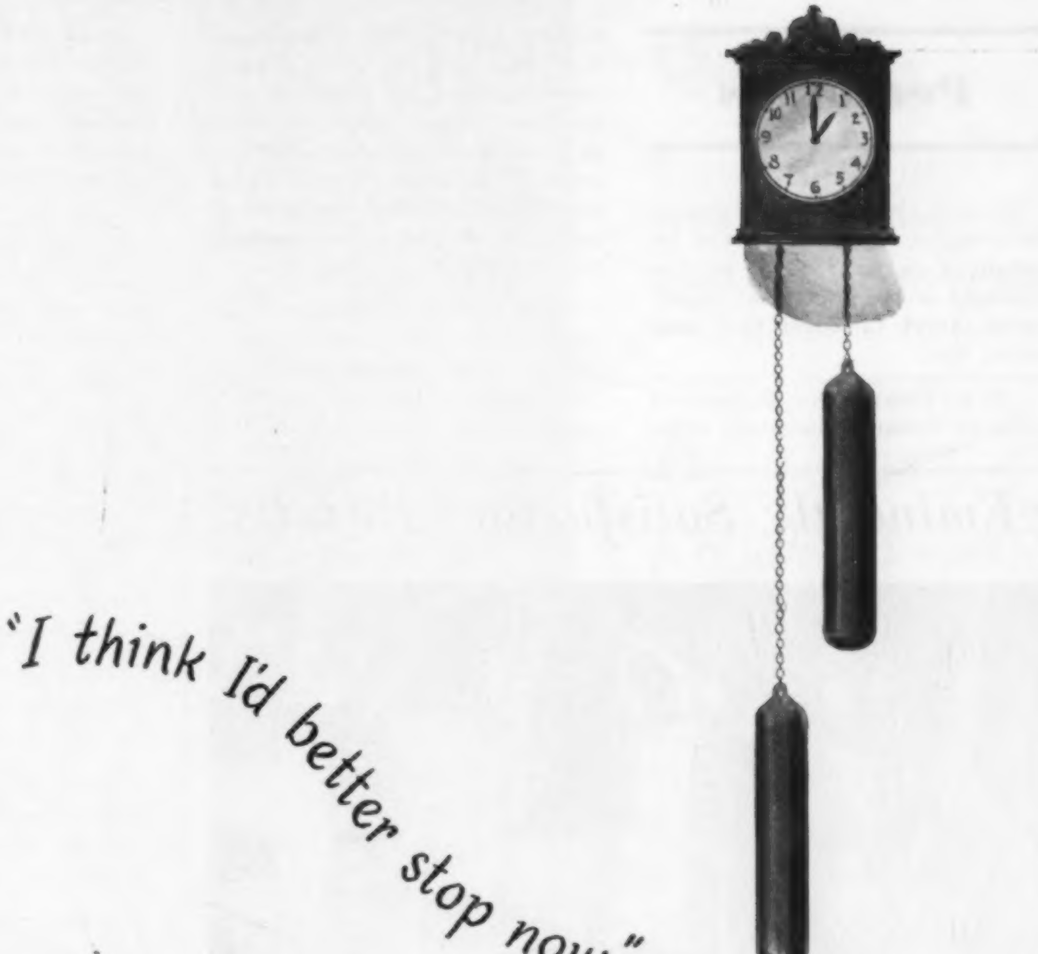
James F. Reid ⊕, former deputy chief of the Alloy Steel Branch of the War Production Board, has been appointed production manager of the Timken Roller Bearing Co.

Paul C. Farren ⊕, formerly chief research metallurgist of the Greenfield Tap and Die Corp., now heads the staff of the Springfield Heat Treating Corp., Springfield, Mass.

George F. Meyer ⊕ has resigned as product metallurgist with the American Steel & Wire Co., Waukegan, Ill., to accept a position as metallurgist with the Illinois Tool Works, Elgin, Ill.

Appointed chief of the Raw Materials Branch, Steel Division, War Production Board: Alex Miller ⊕, formerly chief of the Steel Division's Scrap Section.

Robert Caskie ⊕ has resigned as metallurgist for Beach Foundry, Ottawa, Canada, and has been appointed metallurgist and assistant liam Kennedy & Sons, Ltd., Owen foundry superintendent at the Wil- Sound, Ont., Canada.



When Long Distance Says—

"Please limit your call to 5 minutes"

That's a good suggestion to follow. It means the lines to war-busy centers are crowded. It's a friendly, thoughtful act that helps the other fellow—and then some day turns right around and helps you.

BELL TELEPHONE SYSTEM

Personals

CARL L. WALLFRED ⊕, formerly metallurgist, Battelle Memorial Institute, Columbus, Ohio, is now manager of the pilot plant department, Ansul Chemical Co., Marinette, Wis.

R. H. THIELEMANN ⊕, formerly with the research laboratory of the General Electric Co., Schenectady, N. Y., has been appointed development engineer for Allegheny Ludlum Steel Corp. LAURENCE C. HICKS ⊕, a member of Allegheny Ludlum's research department, has been appointed metallurgical engineer and associate director of research in the Magnetic Products Division.

Transferred by Remington Rand, Inc. Propeller Division: HENRY E. MOORE, JR. ⊕, from the Bridgeport, Conn., plant to Johnson City, N. Y., as supervisor, magnetic inspection.

RICHARD H. TURK ⊕, executi vice-president of the Pemco Corp has been named a member of th National Association of Manufa turers Committee on Veterans Em ployment Problems.

N. H. BRODELL ⊕ has been pr moted by Copperweld Steel Co Warren, Ohio, from metallurgic sales engineer to Cleveland distri sales manager, Steel Division.

WILLIAM C. COOKE ⊕ has bee named sales manager of aerona tical and alloy steel division, Clev land Cap Screw Co.

ANTHONY A. APONICK ⊕, fo merly with the Brown Instrume Co., has been appointed service e gineer in the Buffalo territory f Park Chemical Co.

W. O. EVERLING has been a pointed director of research of th American Steel & Wire Co., Clev land. R. H. BARNES ⊕, former division metallurgist in the meta lurgical department, succeeds M Everling as assistant director research.

JOSEPH BURROUGHS ENNIS senior vice-president, American L comotive Co., New York, was pr sented the George R. Henders Medal of the Franklin Institute f his accomplishments in locomoti engineering and important cont butions in the field of locomoti design.

EARL R. PARKER ⊕ has left t research laboratory of the Gene Electric Co., Schenectady, N. and has joined the staff of the C lege of Engineering, University California.

S. HALPERIN ⊕, formerly assi ant chief metallurgist, Remingt Rand, Inc., Propeller Division, now metallurgist, Morey Machine Co., Astoria, L. I., N. Y.

RAY D. MCMULLIN ⊕, former assistant chief engineer, Andov Motors Corp., Elmira, N. Y., is no chief production engineer wi Lawrance Aeronautical Corp., Li den, N. J.

J. J. VON EDESKUTY ⊕, former assistant development engineer Riley Stoker Corp., Worceste Mass., is now a member of t research staff of General Mills, In Mechanical Division, Minneapol

Personals

William B. Scott ⊕, formerly development engineer for Ampco Metal, Inc., is now metallurgist for Aurora Metal Co., Aurora, Ill.

Elbert A. Hoffman ⊕, formerly with American Steel & Wire Co., is now chief products engineer for La Salle Steel Co., Hammond, Ind.

Edmund S. Davenport ⊕, formerly supervisor of physical metallurgy at the U. S. Steel Corp. Research Laboratory, Kearny, N. J., has been appointed assistant to vice-president, research and technology, with offices in Pittsburgh.

Transferred by American Steel & Wire Co.: Nelson W. Dempsey ⊕, from the South Works at Worcester, Mass., to the Waukegan Works, Waukegan, Ill., as assistant superintendent of the Wire Division, American Steel & Wire Co.

Capt. T. N. Holden ⊕ has r tired from the Army and is place on inactive status, returning to h former business as a sales repr sentative in New York.

L. E. Earnest ⊕, formerly wor manager of Solar Aircraft Co., D Moines, Iowa, is now plant superi tendent, Tube Turns Plant No. Louisville, Ky.

John T. Bryce ⊕ has terminat his connection with Basic Ma nesium, Inc., Las Vegas, Nev., a joined the staff of Howard Found Co., Chicago, as a metallurgic engineer.

Lloyd T. Cheney ⊕ has r signed his position in the stru tures department of Fisher Bo Co., Cleveland, to accept a positi as engineer at the Applied Physi Laboratory of Johns Hopkins Un versity.

Lt. Cdr. K. L. Herrman U.S.N.R., ⊕, has been transferr by the Bureau of Aeronautics to t Western District in Los Angeles work on special surveys of aircra production engineering.

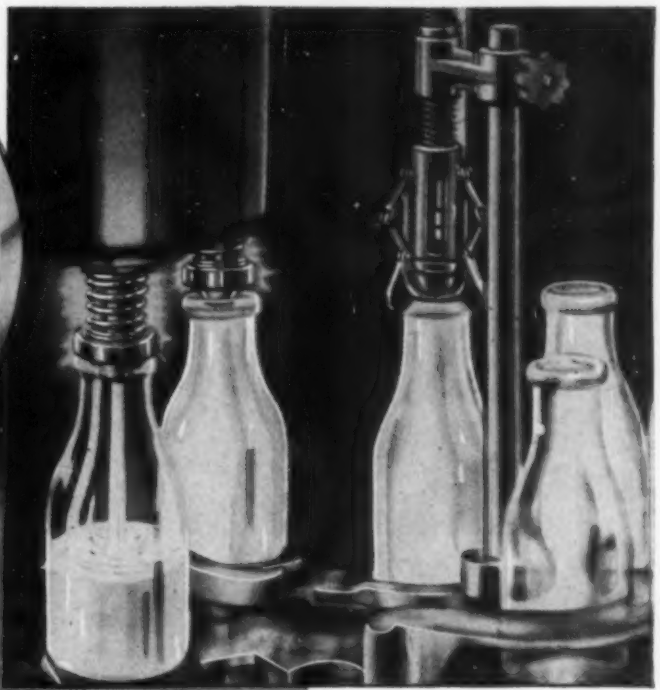
Lewis P. Wilson ⊕, former sand foundry metallurgist and a sistant foreman for the Detr Works of Aluminum Co. of Ame ica, is now chief metallurgist f Oscar W. Hedstrom Corp., Chica

Clarence A. Bowden ⊕, forme metallurgist, Office of Inspector Naval Material, Navy Departme Munhall, Pa., is now associated wi Jessop Steel Co. in the Pittsbur sales office.

Martin J. B. McDonagh ⊕, r cently chief factory inspector f Federal Machine and Welder C Warren, Ohio, has returned American Locomotive Co., Schene tady, N. Y., as production supe visor.

Thomas H. Stancliff ⊕, fo merly assistant chief engineer, Re Roller Bit Co., is now with Glo Oil Tools Co. as vice-president i charge of research and engineerin

Charles F. Johnson ⊕, fo merly manager of the valve div sion, Reed Roller Bit Co., is no manager of the valve division f Security Engineering Co., Whittie Calif.



Structure of Cementite

(Continued from p. 1118) the iron-carbon bond is probably similar in each case. This suggests, among other things, that, while cementite has normally attributed to it the nature of a chemical compound, a supposition supported by its apparent constancy of composition, it is in fact to be expected that it will have many of the characteristics of a solid solution. It might be then expected that the composition may not be exactly constant."

To test this assumption a 1.8% carbon-iron alloy was melted from very high purity iron and graphite, many precautions being taken to prevent contamination and gas absorption during melting and heat treatment. Cementite was extracted electrolytically from samples after annealing and after drastic quenching from various temperatures. Chemical analysis of this residue failed to show significant differences, and the lattice parameters remained constant, within the experimental error of ± 0.0005 Å, as long as the cementite was in equilibrium with ferrite. Systematic variation was, however, shown when the cementite was in equilibrium with austenite, thus:

Quenching Temperature	Change in Lattice *a*	*b*	*c*
750° F.	+0.0001	0	+0.0001
1255	+0.0003	−0.0002	+0.0003
1380	−0.0020	−0.0015	+0.0017
1560	−0.0050	−0.0045	+0.0037
1650	−0.0067	−0.0052	+0.0047

These changes could not be due to quenching stresses, since the spectral lines were quite sharp, characteristic of an unstrained substance. Composition variance is therefore due to changes in carbon, for the methods of test precluded contamination by alloying metal or gas.

From these considerations it would appear that cementite is like the "interstitial structures", the carbides, nitrides and borides of the transition elements studied by Hägg in 1931 *(Zeitschrift für physikalische Chemie)*. All these structures demand close packing of the metallic atoms, and no limitation is imposed by the non-metallic atoms on the number or distribution of their metallic neighbors. (In this they are akin to austenite, where the iron framework can exist even when the carbon atoms are missing.) The stable structure of cementite is simply the one which can achieve close packing, and the stable composition is the one required to build this structure. In the iron-carbon system this occurs at 3Fe:1C. Great variation from this ratio would not be expected. The usual type of composition variation arising from the replacement of one component by another is not possible, on account of the difference in atomic size of iron and carbon. However, a few carbon atoms might be omitted, with a few dimensional changes in the unit cell.

Magnesium

(Cont. from p. 1110) not be as larg at the present time as the curv indicates.

Dross and porosity account fo 75 to 90% of the total rejections o aluminum and magnesium casting When the low rate of rejection shown in Fig. 7 is reached, th rejection is still due to either dros or porosity. Unfortunately, dros inclusions (if exposed) serve as th starting points of corrosion. Elimination of this danger is altogether metallurgical problem. *Porosity*, o the other hand, can be traced eithe to processing or to design. Porosit through processing is caused b evolution of gases, often manifesting itself as very small voids, more or-less generally distributed. It i generally accepted that porosit due to the design is caused b excessive temperature gradient during cooling. In one case, th problem is strictly metallurgical in the second it needs the combine efforts of a metallurgist and designer.

Whatever the reason, th presence of imperfections (eve though they occur only occasionally) is a serious matter from th viewpoint of structural strength The only recourse would be 100 X-ray inspection. Even this costl procedure has basic limitation First, we must realize that X-ra photography and interpretatio requires experience and knowledge unless the interpretation is intelligent, the value of X-ray examination in all but obviously defectiv castings is lost.

Then, unfortunately, present day magnesium casting alloy exhibit basic properties which ar markedly affected by the presence of minute cavities or inclusions These basic properties concern sensitivity to notch impact, lov fatigue strength (10,000 psi. a most) and low ductility (6 or 7% in 2 in.). Realizing these basic characteristics it becomes increasingly difficult to evaluate what additional uncertainty might no be introduced through the presence of even isolated defects. All o these factors, which we hold pertinent to our work, led the Lockheed organization to conclude that the most vital action is adequate metallurgical control.

Sound the Alert!

MANAGEMENT • LABOR

—for the 5th War Loan drive during June and July. The need for the 5th War Loan is immediate, crucial. For impending events may make the 5th the supreme financial effort of the war.

The U. S. Treasury has set the overall goal at $16,000,000,000 — $6,000,000,000 from individuals alone. This is the biggest sum ever asked of the American people—*and it must be raised.*

That's why the U. S. Treasury asks Management and Labor to sit down together and organize—NOW!

For organization—good organization—has been responsible for the excellent showing of the payroll market. And its most important single superiority has been personal solicitation—desk to desk, bench to bench, machine to machine personal solicitation. 71% of all persons on payroll deductions were solicited for the 4th War Loan.

Now, to personal solicitation, add the sales incentive of a definitely established plant quota. Build your campaign around a quota plan. Set up departmental goals. Stress percentage of participation figures. Stimulate group enthusiasm.

In planning your quota campaign, work in close cooperation with the Chairman of your War Finance Committee. Everything is set to make the 5th War Loan drive a huge success—with your help!

(Note: You've read this message. If it doesn't apply to you please see that it reaches the *one* person who can put it in action!)

Here's the Quota Plan:

1. Plant quotas are to be established on the basis of an *average* $100 *cash* (not maturity value) purchase per employee.
2. Regular Payroll Savings deductions made during the drive accounting period will be credited toward the plant quota.
3. 90% of the employees are expected to contribute toward raising the cash quota by buying extra 5th War Loan Bonds: 1—Outright by cash. 2—By extra installment deductions. 3—By extra installment deductions plus cash.

Example: **JOHN DOE Mfg. Co.** — 1,000 Employees

1,000 employees x $100	=	$100,000 Cash Quota
Regular Payroll deductions during the eight weekly payroll Accounting Periods of June and July		30,000
		$70,000 (to be raised by sales of extra Bonds to at least 900 employees)

ORGANIZE • SOLICIT • DELIVER

The Treasury Department acknowledges with appreciation the publication of this message by

American Society for Metals

★ ★ *This is an official U. S. Treasury advertisement—prepared under the auspices of Treasury Department and War Advertising Council.* ★ ★

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

METAL WORKING • FABRICATION

Marvel metal cutting saws. Armstrong-Blum Mfg. Co. Bulletin 395.

Powdered metal presses. Kux Machine Co. Bulletin 1.

Forging presses. Ajax Mfg. Co. Bulletin 2.

Horizontal extrusion presses. Hydropress, Inc. Bulletin 3.

36-page pictorial story of the Cecostamp. Chambersburg Engineering Co. Bulletin 4.

Cutting Oils. Cities Service Oil Co. Bulletin 5.

Presses for Powder Metallurgy. F. J. Stokes Machine Co. Bulletin 7.

Information and data on straightening press. Anderson Bros. Mfg. Co. Bulletin 10.

Properties and uses of cutting oils. Gulf Oil Corp. Bulletin 8.

Surface coated abrasive belts. Minnesota Mining & Mfg. Co. Bulletin 12.

Savings in oils, tool bits, grinding wheels. Sparkler Mfg. Co. Bulletin 15.

New catalog illustrates standard, non-standard, and special tools. Kennametal, Inc. Bulletin 250.

Mounted wheels, Handee and Hi-Power tools. Chicago Wheel & Mfg. Co. Bulletin 21.

Air tools in steel mills and foundries are pictured in new booklet by Ingersoll-Rand. Bulletin 255.

Big, comprehensive catalog illustrates line of power presses offered by Minster Machine Co. Bulletin 320.

Complete and valuable study of "Machining of Metals", including chip formation, is offered by National Refining Co. Bulletin 335.

Safe-T tongs and their use in materials handling are described in new booklet by Heppenstall Co. Bulletin 434.

63-page pocket booklet shows useful tables of weights and measures used in the metal industry. Mesta Machine Co. Bulletin 441.

Practical data sheet describes cutting and grinding compound. Diversey Corp. Bulletin 447.

8-page general catalog outlines the hard facing alloys and overlay metals of this company, with many illustrations and typical applications. Wall-Colmonoy Corp. Bulletin 484.

This company has issued two new booklets showing new price lists for sintered carbides. Firth-Sterling Steel Co. Bulletin 486.

"Quality Control" is the title of this new 64-page pocket size handbook on scientific inspection. Continental Machines, Inc. Bulletin 479.

20-page booklet discusses typical problems involved in the selection and application of water-mix oils. D. A. Stuart Oil Co., Ltd. Bulletin 482.

Attractive new bulletin describes the Spencer Turbine Co.'s Sump-Vac, a new portable vacuum producer which is said to clean machine sump tanks in 2 to 10 min. Bulletin 494.

FERROUS METALS

Republic Steel Corp.'s second edition of National Emergency Steels tells you all about these new steels. Bulletin 345.

Page after page of useful technical data and reference tables on tool steels. Latrobe Electric Steel Co. Bulletin 367.

Steel Data Sheets. Wheelock, Lovejoy & Co. Bulletin 25.

Use Handy Coupon Below for Ordering Helpful Literature.

Other Manufacturers' Literature Listed on Pages 1174, 1176, 1178, 1180, 1182, 1184, 1186, 1188, 1190, 1192, 1194, 1196 and 1198.

Metal Progress 7301 Euclid Ave., Cleveland 3, Ohio June, 1944

Send me the Literature I have indicated below.

Name .... **Title** ....

Company .... **Address** ....

(Students—please write direct to manufacturers).

Check or circle the numbers referring to literature described on these 14 pages.

1	45	86	119	155	185	246	322	360	390	438	465	489	509
2	48	89	122	156	186	250	323	361	395	439	466	490	510
3	51	93	123	158	189	255	324	362	398	440	468	491	511
4	56	94	128	161	190	258	325	363	399	441	469	492	512
5	57	96	132	162	192	271	327	364	404	445	470	493	513
7	59	97	134	163	193	281	328	365	406	446	471	494	514
8	62	98	135	164	197	284	329	366	407	447	472	495	515
10	65	99	137	167	199	288	330	367	409	448	473	496	
12	66	101	139	170	200	291	331	368	410	449	475	497	
15	67	102	141	171	201	292	333	369	411	450	477	498	
21	70	103	142	172	202	296	335	372	414	452	478	499	
25	71	105	143	173	203	297	337	374	420	453	479	500	
26	72	106	144	174	204	301	338	375	422	454	480	501	
30	76	107	146	175	206	305	339	376	424	455	481	502	
31	78	109	147	176	208	307	343	377	426	457	482	503	
33	79	114	148	177	210	314	345	380	428	458	483	504	
35	82	115	149	179	212	316	347	383	433	459	484	505	
40	83	116	150	180	213	318	353	384	434	461	485	506	
41	84	117	152	182	215	319	354	385	436	462	486	507	
42	85	118	154	183	240	320	359	388	437	463	487	508	

MISCO

HIGH TEMPERATURE ALLOY

Sheet Carburizing

BOXES

Please turn to page 1028

Other MISCO Products

Furnace Parts • Roller Rails • Conveyors • Roller Hearths • Conveyor Rolls • Trays • Retorts • Thermocouple Protection Tubes • Chain • Walking Beam Conveyors • Carburizing and Annealing Boxes • Dipping Baskets • Cyanide and Lead Pots • Centrifugal Castings and Miscellaneous Castings for use at high temperature or under corrosive conditions.

★

INVEST all you can in WAR BONDS

THE construction of Misco High Temperature Alloy Sheet Carburizing Boxes is planned for most efficient service. Misco Sheet Boxes are at least 50% lighter than cast boxes of equal capacity. Thermal stresses are reduced and pound for pound they last longer. Misco Sheet Boxes heat rapidly, save fuel, and reduce handling time. Based on our experience with thousands of carburizing boxes of all types, Misco Sheet Boxes afford maximum service per dollar of investment, and provide the greatest output in a given period of time . . . We will be pleased to furnish you with complete details regarding the many advantages of Misco Sheet Carburizing Boxes.

MISCO
Heat and Corrosion Resistant Alloys

Michigan Steel Casting Company

One of the World's Pioneer Producers of Heat and Corrosion Resistant Alloy Castings

1999 GUOIN STREET, DETROIT 7, MICHIGAN

WHAT'S NEW

IN MANUFACTURERS' LITERATU

Molybdenum wrought steel Molybdenum Corp. of America. Bu letin 26.

Free Machining Steels. Monar Steel Co. Bulletin 30.

Chemical analyses, shapes a sizes of Joslyn stainless steel pro ucts. Joslyn Mfg. and Supply C Bulletin 297.

Tool Steels. Bethlehem Steel C Bulletin 31.

Enameling iron sheets. Inla Steel Co. Bulletin 33.

Loose-leaf reference book on m lybdenum steels. Climax Molybd num Co. Bulletin 35.

Aircraft Alloy Steels. Joseph Ryerson & Son, Inc. Bulletin 40.

Kinite alloy tool steel bar stock. Boker & Co., Inc. Bulletin 258.

New Catalog C makes it easy to International Nickel Co. literature, it presents brief description and i dex to a wide variety of bookle Bulletin 305.

"Graphitic Booklet" gives comple information on new, free-machinin long-wearing steel. Steel & Tu Div., Timken Roller Bearing C Bulletin 307.

HWD hot work die steel and Ste ling stainless steels are described four new leaflets by Firth-Sterli Steel Co. Bulletin 323.

Engineering and comparative i formation on porcelain enamel iron is presented in new illustra booklet by American Rolling Mill C Bulletin 376.

New booklet gives full informati on N-A-X high tensile and N-A 9100 Series of alloy steels. Gr Lakes Steel Corp. Bulletin 328.

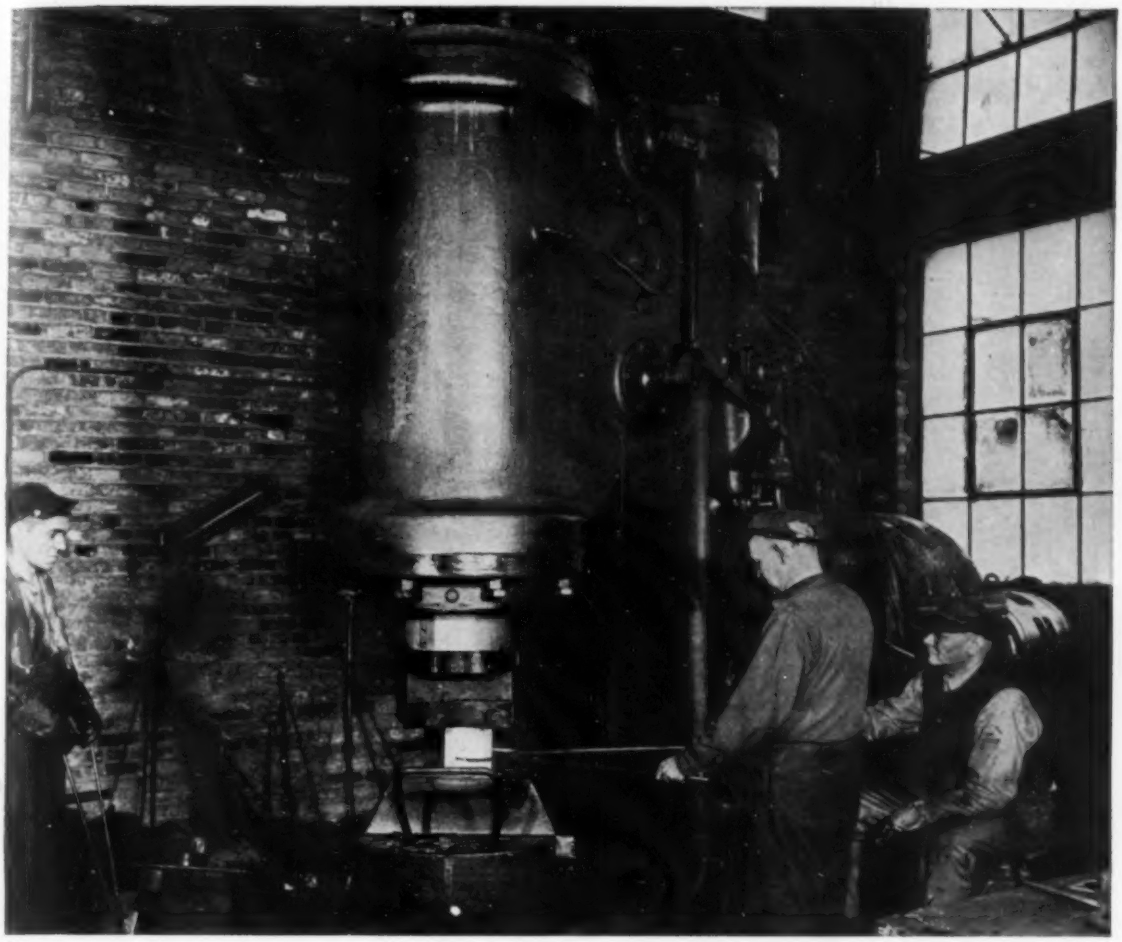
Attractive new catalog descri the line of steel offered by Pen sular Steel Co. Bulletin 337.

Spindle speed calculator is han chart to figure machining rates bar steels. Bliss & Laughlin, I Bulletin 333.

64-page booklet describes t welding of stainless steels. Al gheny Ludlum Steel Corp. Bulle 384.

84-page tool and die steel handbo just issued by Ziv Steel & Wire C is a helpful guide to selection, tre ment and use of these importa steels. Bulletin 440.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature.
Other Manufacturers' Literature Liste on Pages 1172, 1176, 1178, 1180, 1182, 11 1186, 1188, 1190, 1192, 1194, 1196 and 11



AN INDEPENDENT, SELF-CONTAINED FORGING HAMMER

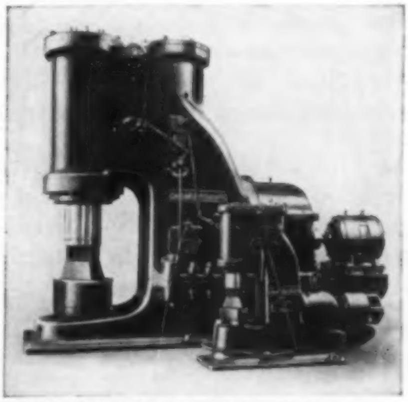
• BUILT BY CHAMBERSBURG •

BACK of this modern, self-contained electro-pneumatic hammer is nearly half-a-century of experience gained in the design and manufacture of forging hammers of all types and sizes. This pneumatic hammer therefore is a *better* hammer, designed for installation where steam lines or air lines are not convenient or where the location of the hammer may be subject to change. It is fully self-contained, the compressor unit being a part of the hammer itself. In operation the ram is driven up and down by flexible air force, created by the compressor piston, which, in turn, is driven by an electric motor of high speed through two-stage speed reduction gearing. The hammer can be started instantly and strikes a constant number of blows, heavy or light, at the will of the operator. As soon as the motor is up to speed the hammer is ready to operate. Power is consumed only while the hammer is operating.

Write today for a copy of Bulletin 1275

Chambersburg Pneumatic Forging Hammers are built in three types:

1. ONE PIECE, having the anvil integral with the frame. Sizes rated at 200 lbs. and 300 lbs.
2. SOLID FRAME, having separate anvil and a one-piece frame. Sizes 300 lbs. and 500 lbs.
3. TWO-PIECE FRAME, having separate anvil with frame mounted on base plate which encircles anvil. Sizes 750 lbs. and up.



CHAMBERSBURG ENGINEERING CO. **CHAMBERSBURG, PA.**

ARMY E NAVY

CHAMBERSBURG

HAMMERS · CECOSTAMPS · PRESSES

WHAT'S NEW

IN MANUFACTURERS' LITERATU

32-page booklet which pictorial and textually amounts to a scientif treatise on two carbon steels—Spe Case and Speed Treat—has been i sued by W. J. Holliday & Co. Bull tin 450.

Fitzsimons Co. issues interestin leaflet on speed case and speed tre steels. Bulletin 452.

Molybdenum-Tungsten high spe steels marketed under the gener trade name Mo-Max are discusse comprehensively in 52-page book b J. V. Emmons, metallurgist for th Cleveland Twist Drill Co. Bulleti 497.

Carpenter Steel Co. offers a con venient four-color chart useful i identifying various types of stainle steels which may have become mixe in stock. Bulletin 507.

NON-FERROUS METALS

This "Aluminum Imagineerin Notebook" presents 12 importa economic advantages of aluminu and illustrates numerous example of things which have been imag neered into aluminum actualitie Aluminum Co. of America. Bulleti 472.

80-page pipe and tube bendi handbook has been issued by Copp & Brass Research Assn. Bulletin 39

Platinum Metal Catalysts. Baker Co., Inc. Bulletin 41.

Die casting equipment. Leste Phoenix, Inc. Bulletin 42.

Copper Alloys. American Brass C Bulletin 45.

Brass and bronze castings. Ha mond Brass Works. Bulletin 48.

6th edition of Revere Weights an Data Handbook. Revere Copper an Brass, Inc. Bulletin 296.

Rare metals, alloys and ores. Foo Mineral Co. Bulletin 56.

Brazing Booklet. Westinghous Elec. & Mfg. Co. Bulletin 57.

Dowmetal data book. Dow Chemi cal Co. Bulletin 51.

Two new Ampco Metal data shee discuss forging Ampco to impro physical characteristics and use o Ampco for non-scratching feed fin gers. Bulletin 314.

20-page book shows each step i production of brass and aluminu castings by Manufacturers Bras Foundry Co. Bulletin 414.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature.
Other Manufacturers' Literature Listed on Pages 1172, 1174, 1178, 1180, 1182, 118 1186, 1188, 1190, 1192, 1194, 1196 and 119

OUR INVASION TEAM

Official U. S. Marine Corps News Photo by Acme

When G. I. Joe hits the invasion beach, much of his equipment . . . from landing barges and motorized equipment that spearhead his advance, to planes that form a protective canopy over him . . . will have component parts made from aluminum alloys. And back of our invading soldiers stand the home-front workers whose conservation of aluminum scrap collected in manufacturing processes and kept carefully segregated, insures adequate supplies of these war-vital alloys.

But this teamwork would be incomplete without the teamwork in the smelters' own plants . . . teamwork that insures these new alloys meeting rigid quality specifications. By means of close cooperation between the laboratories and the production department it is possible to re-alloy this aluminum scrap into closely controlled ingot of proven quality.

This same controlled quality will benefit foundries postwar . . . enabling them to make better castings at minimum cost for better civilian products.

Aluminum and Magnesium, Inc.
Sandusky, Ohio

The American Metal Company, Limited
New York City 6

Apex Smelting Co.
Chicago 12, Illinois

The Cleveland Electro Metals Co.
Cleveland 13, Ohio

Federated Metals Division American Smelting and Refining Company
New York City 5 and Branches

General Smelting Company
Philadelphia 34, Pennsylvania

Samuel Greenfield Co., Inc.
Buffalo 12, New York

William F. Jobbins, Inc.
Aurora, Illinois

R. Lavin & Sons, Inc.
Chicago 23, Illinois

The National Smelting Company
Cleveland 5, Ohio

Niagara Falls Smelting & Refining Corp.
Buffalo 17, New York

Sonken-Galamba Corporation
Kansas City 18, Kansas

U. S. Reduction Co., *East Chicago, Indiana*

ALUMINUM RESEARCH INSTITUTE

111 West Washington Street, Chicago 2, Illinois

BUY BONDS

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

"Designing with Magnesium" is title of new book offered by American Magnesium Corp. Bulletin 433.

Red-X Aluminum Alloys, produced by the largest single producer of Commercial Aluminum and Magnesium Alloys, the National Smelting Co., are described, applications studied, in this 16-page file folder. Bulletin 499.

Facts on Beryllium Copper, including composition, forms available, applications and extensive additional information are presented in this new 16-page booklet by the Riverside Metal Co. Bulletin 511.

WELDING

40-page catalog reviews the progress and many applications of low temperature welding. Eutectic Welding Alloys Co. Bulletin 471.

Welding Stainless. Page Steel & Wire Div., American Chain & Cable Co., Inc. Bulletin 59.

Oxy-acetylene welding and cutting. Linde Air Products Co. Bulletin 62.

Welding and brazing of aluminum, a new data book issued by Aluminum Co. of America. Bulletin 66.

Data book facts on spot, seam and flash welding ferrous and non-ferrous metals and alloys. P. R. Mallory & Co., Inc. Bulletin 65.

Shield Arc electrodes. McKay Co. Bulletin 67.

Nu-Braze No. 4, an improved silver brazing alloy. Sherman & Co. Bulletin 288.

Two new hard-facing alloys furnished as welding rods for application by Oxy-Acetylene process are described by the Stoody Co. in Bulletin 325.

Comparable arc welding electrodes for stainless are shown in chart issued by Alloy Rods Co. Bulletin 353.

Helpful electrode color chart is offered by the Arcos Corp. Bulletin 374.

Arc welding inspection chart, designed so that operators can tell at a glance whether welds are being properly made, has been issued by the Lincoln Electric Co. Bulletin 411.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature. Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1180, 1182, 1184, 1186, 1188, 1190, 1192, 1194, 1196 and 1198.

WHAT'S NEW

IN MANUFACTURERS' LITERATU

New Phos-Copper booklet expla ways to braze, design and appli tions. Westinghouse. Bulletin 4

16-page booklet describes welding and cutting equipme Victory Equipment Co. Bulletin 4

Bulletin No. 14, "How To Rep Broken Cutting Tools With Ea Flo", is filled with practical, instr tional copy, profusely illustrat Handy & Harman. Bulletin 506.

Air Reduction Sales Co. off 20-page revised price list, "Gas a Electric Welding Supplies and Acc sories". Bulletin 512.

32-page booklet presents numer experience reports from large us of arc welding. General Electric (Bulletin 513.

TESTING & INSPECTION

Latest technical literature on x-r and radium protection, together wi lead products catalog, has been sued by Bar-Ray Products, Inc. B letin 463.

The Bristol-Rockwell dilatome and its use is described in th leaflet by The Bristol Co. Bulle 465.

250 KV industrial x-ray units jib crane, mobile and dolly— described in this new bookl Picker X-Ray Corp. Bulletin 468.

Metallurgical polishing equipme offered by Precision Scientific Co is described in illustrated bookl Bulletin 359.

Various methods and specific a plications of the measurement of ca depth are described in illustrat pamphlet offered by Allen B. DuMo Laboratories, Inc. Bulletin 339.

Bibliography of more than 7 papers dealing with the polar graphic method of metal analysis an a booklet discussing this equipme is offered by E. H. Sargent & C Bulletin 338.

SR-4 strain gage and illustratio of its many uses. Baldwin Sout wark. Bulletin 70.

New book contains wealth of pra tical, usable information on indu trial inspection by x-ray. Westin house Electric & Mfg. Co. Bulletin 7

Use Handy Coupon on Page 1172 for Ordering Helpful Literature.
Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1178, 1182, 118 1186, 1188, 1190, 1192, 1194, 1196 and 119

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

X-Ray Diffraction Unit. General Electric X-ray Corp. Bulletin 72.

Inspection of non-magnetic metals with the new Zyglo method. Magnaflux Corp. Bulletin 78.

Industrial radiography with radium. Canadian Radium & Uranium Corp. Bulletin 79.

Gage blocks, comparators, projectors. George Scherr Co. Bulletin 83.

Portable Brinell hardness tester and folding Brinell microscope. Andrew King. Bulletin 85.

Universal testing machines and typical uses. Riehle Testing Machine Div., American Machine and Metals, Inc. Bulletin 86.

Optical Aids. Bausch & Lomb Optical Co. Bulletin 94.

Metallographic polishing powder. Conrad Wolff. Bulletin 96.

Metallurgical Equipment. Adolph I. Buehler. Bulletin 97.

"Radiography of Materials" is title of new 96-page book on industrial radiography. Eastman Kodak Co. Bulletin 331.

Stresscoat, a method of analyzing distribution, direction and value of local strains. Magnaflux Corp. Bulletin 301.

Hardness testing equipment. Wilson Mechanical Instrument Co., Inc. Bulletin 98.

Attractive, illustrated booklet describes Clark Instrument's precision hardness tester. Bulletin 318.

Two new folders describe Searchray 80, new self-contained X-ray unit of North American Philips Co. Bulletin 377.

High intensity industrial illuminator is illustrated and described in new leaflet by Kelley-Koett Mfg. Co. Bulletin 406.

30th Anniversary Catalog shows the special metallurgical equipment offered by Claud S. Gordon Co. Bulletin 410.

Laboratory and industrial pH meters are described and explained in leaflet issued by Beckman Instruments Division. Bulletin 422.

8-page illustrated leaflet describes line of industrial instruments offered by the Brush Development Co. Bulletin 428.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature. Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1178, 1180, 1184, 1186, 1188, 1190, 1192, 1194, 1196 and 1198.

One of a series of articles on the preparation of metal surfaces for protective finishes

INFORMATION ON SPECIFIC CLASSES OF PICKLING

Wire Pickling

From safety pins and bobby pins to the coiled springs in the easy chairs and the mighty steel cables that sustain suspension bridges — all wire must withstand the stress of bending, coiling and twisting as well as tensile strain.

Not only must the correct analysis for the metal be chosen but the treatment in reducing it to its proper size and form must not impair the quality. The transformation from the steel bar to the tough, slender wire requires expert knowledge and handling.

Pickling of wire, while an important step, is an old practice, and as such, often fails to receive proper consideration. Pickling should be done in such a manner that the metal will not be injured. In other words, the acid bath should be made to confine its action to its ascribed purpose, the removal of scale and rust, and be prevented from unduly dissolving and etching the clean metal.

Though the saving in acid and metal, which Rodine makes possible, is a factor responsible for its so general use, there are, however, other factors that at times are of even greater importance. Rodine, in markedly reducing the hydrogen evolved on the metal, logically reduces the amount that can be absorbed into the crystalline structure. It is the absorbed hydrogen that causes the embrittlement of steel wire, bars, springs, etc. It is this absorbed hydrogen that expands in the laminations and faults in sheets giving rise to blisters. Both of these conditions are minimized with Rodine through control of the acid's action.

In the wire industry, use of new Rodine has so reduced the embrittling effect as to make possible merely drying lime coatings in a flash baker in a few minutes instead of baking for many hours in the old-type baker.

Sheet and Strip Steel

In the steel industry, millions of tons of sheets and strip are pickled annually. The savings in acid and metal, due to Rodine control of the acid bath, on these large tonnages are huge. Savings in acid and metal are, however, not the only economies that Rodine effects. The savings due to minimizing the scrapping of blistered sheets and reducing the rejections of sheets or strips due to excessively pitted surfaces, with the resultant increase in tin or spelter required to fill pits in the surface, are important though frequently overlooked.

Pickling Alloy and High Carbon Steel—Stainless Steel

Alloy and high carbon steels are difficult to pickle. They are attacked rapidly by the acid and, as a result, the surface is roughened and blackened. This violent attack is due largely to the dissimilarity of contacting crystals in the alloys which in the pickling bath form electrolytic couples that in turn set up countless electric currents. These augment the acid's attack on the less noble crystals, thereby preferentially dissolving them and cause the metal to be rough and usually deeply pitted. To offset these characteristics of alloy and high carbon steels, it is of utmost importance to use Rodine. The addition of rock salt to the sulphuric acid pickling bath will lead to better pickled surfaces of alloy steels.

Pickling Machined and Polished Steel

Rust or oxidization from heat treating can be pickled from machined or polished steel without marring the high finish, when Rodine is employed. Even polished and threaded objects may be pickled in a Rodine inhibited bath without damaging threads or changing the dimensions of the work.

Pickling to Remove Metal Coatings

In pickling to remove metal coatings, such as zinc, from defective galvanized steel, Rodine prevents the acid from attacking the basis metal without retarding the stripping action.

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

Details and various applications of the portable tensile tester are shown in 8-page leaflet by W. C. Dillon & Co., Inc. Bulletin 491.

Advantages and speed of testing with the Magnetic Analysis Corp.'s Comparator are described and pictured in brochure just released. Bulletin 492.

6-page leaflet describes the constant temperature equipment offered by American Instrument Co. Bulletin 493.

New Carbon and Sulphur Determinator is described in this new 8-page leaflet. Harry W. Dietert Co. Bulletin 501.

Many tips and suggestions for industrial laboratories are presented in 24-page March issue of "Curves and References" by Wilkens-Anderson Co. Bulletin 502.

4-page folder on the inspection and control of surface finish is offered by George Scherr Co. Bulletin 508.

TEMPERATURE CONTROL

New 29-page catalog — Micromax Electric Control — has just been issued by Leeds & Northrup Co. Bulletin 76.

Potentiometer temperature indicators. Foxboro Co. Bulletin 82.

Micro-Optical Pyrometers. Pyrometer Instrument Co. Bulletin 89.

Pyrometer control of high speed salt baths is described in new booklet by Brown Instrument Co. Bulletin 324.

Pyrometer Controller. Illinois Testing Laboratories, Inc. Bulletin 84.

Industrial thermocouples. Arklay S. Richards Co. Bulletin 93.

Operating principle and types available of the synchronous-motor-driven cam program timer are covered in this new 4-page folder. Automatic Temperature Control Co., Inc. Bulletin 487.

36-page thermocouple data book and catalog describes products, prices and presents recommendations for thermocouple users. Wheelco Instruments Co. Bulletin 490.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature.
Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1178, 1180, 1182, 1186, 1188, 1190, 1192, 1194, 1196 and 1198.

WHAT'S NEW

IN MANUFACTURERS' LITERATU

The Bristol Co. announces a bulletin B220 describing its new of Free-Vane Electronic Control for temperature, pressure, li level and humidity. Bulletin 503

48-page revised catalog, "Micro and Speedomax Rayotube Pyr eters", pictures applications of equipment to important new t perature-measuring jobs. Leed Northrup Co. Bulletin 514.

HEATING • HEAT TREA MENT

"Isothermal Quench Baths App to Commercial Practice" is the of this 12-page paper, a practi and useful discussion of S curve heat treatment. Ajax Electric Inc. Bulletin 461.

32-page booklet describes 16 in esting industrial uses of high quency electrical induction. Crankshaft Co. Bulletin 459.

Quenching oil coolers in heat tr ing practices are described in leaflet by the Sims Co. Bulletin

New catalog No. 406 descri Rockwell valves for control of gas and liquids. W. S. Rockwell Bulletin 466.

Neutral baths for heat treatn and details of their use are descri in this booklet by the A. F. Ho Co. Bulletin 469.

24-page technical data and ope ing manual covering the Deepfr low temperature industrial chi machines has been issued by D freeze Div., Motor Products C Bulletin 398.

36-page catalog illustrates K Hold line of thermal, sub-zero stratosphere processing and tes machines. Kold-Hold Mfg. Co. Bu tin 99.

Induction heating. Induction H ing Corp. Bulletin 103.

Internally heated salt bath furn and pots. Upton Electric Furn Div. Bulletin 102.

Easy-selection charts on burning equipment. National chine Works. Bulletin 105.

Use Handy Coupon on Page 117
for Ordering Helpful Literature.
Other Manufacturers' Literature Li
on Pages 1172, 1174, 1176, 1178, 1180, 1
1184, 1188, 1190, 1192, 1194, 1196 and 1

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

8-page pictorial bulletin describes the heat treating service of Continental Industrial Engineers, Inc. Bulletin 107.

Electric Furnaces. Ajax Electrothermic Corp. Bulletin 106.

Lithco, the chemically-neutral heat treating process, and Lithcarb, the process for fast, bright gas-carburizing. Lithium Corp. Bulletin 101.

Furnaces for heat treatment of aluminum, magnesium and their alloys. Lindberg Engineering Co. Bulletin 271.

Gas, oil, and electric heat treating and carburizing furnaces. Holcroft & Co. Bulletin 114.

Industrial furnaces, equipment for bright annealing stainless steels and ammonia dissociation equipment. Drever Co. Bulletin 115.

Industrial ovens, rod bakers, welding rod ovens, furnaces. Carl-Mayer Corp. Bulletin 116.

Full muffle and other heat treating furnaces described in catalog by Charles A. Hones, Inc. Bulletin 117.

Non-metallic Electric Heating Elements. Globar Div., Carborundum Co. Bulletin 119.

56-page vest pocket data book on heat treating practices and procedures. Chicago Flexible Shaft Co. Bulletin 118.

Control of temperatures of quenching baths. Niagara Blower Co. Bulletin 122.

Molten Salt Baths. E. I. duPont deNemours & Co., Inc., Electrochemicals Department. Bulletin 123.

Handling cylinder anhydrous ammonia for metal treaters. Armour Ammonia Works. Bulletin 128.

Certain Curtain Furnaces. C. I. Hayes, Inc. Bulletin 134.

Air-Oil Ratiotrol for proportioning flow of fuel oil and air to oil burners. North American Mfg. Co. Bulletin 135.

Two new bulletins on vertical carburizers and on carbonia finish. American Gas Furnace Co. Bulletin 139.

*Van Norman induction heatin*g units. Van Norman Co. Bulletin 14

*Controlled atmosphere furnac*e Delaware Tool Steel Corp. Bulleti 141.

Dual-Action quenching oil. Gu Oil Co. Bulletin 132.

Furnaces. Tate-Jones Co. Bulleti 142.

Industrial Carburetors. C. M. Kem Mfg. Co. Bulletin 143.

Heat treating, brazing and mel ing of ferrous and non-ferrous me als. Lepel High Frequency Labor tories, Inc. Bulletin 147.

Vertical Furnace. Sentry Co. Bu letin 148.

Conveyor Furnaces. Electric Fu nace Co. Bulletin 149.

High and low temperature dire fired furnaces. R-S Products Cor Bulletin 146.

New Electric Furnace. America Electric Furnace Co. Bulletin 15

Electric Furnaces for laborator and production heat treatment. Ho kins Mfg. Co. Bulletin 152.

"The Lectrodryer in the metallu gical industries," a new 4-page bu letin by Pittsburgh Lectrodryer Cor Bulletin 155.

Pictorial bulletin describes fu naces for heat treating, normalizin annealing, forging. Vulcan Cor Bulletin 161.

High Temperature Fans. Michia Products Corp. Bulletin 158.

*Protective combusted atmospher*e in Hevi Duty Electric Co. furnac are discussed in 12-page Bulletin 31

Flame-type mouth and taper a nealing machine for steel cartrid cases. Morrison Engineering Cor Bulletin 154.

*Turbo-Compressor data bo*ok shows how to calculate compress air systems for a dozen different a plications. Spencer Turbine Co. Bu letin 329.

No-Carb, a liquid paint for preve tion of carburization or decarburi tion. Park Chemical Co. Bullet 156.

Catalog of heat treating materia Heatbath Corp. Bulletin 322.

Standardized sizes of semi-muf and pot-type furnaces are describe and pictured in new leaflet by Dem sey Industrial Furnace Corp. Bu letin 354.

Use of pulverized coal in the meta lurgical industries, equipment an designs, are described by Amsle Morton Co. in Bulletin 361.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature.

Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1178, 1180, 118 1184, 1186, 1190, 1192, 1194, 1196 and 11

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

82-page catalog describes in detail General Electric heat treat furnaces. Bulletin 380.

Illustrated bulletin on stress-relieving, car-type furnaces. Radiant Combustion. Bulletin 375.

Furnaces for heat treating tools, dies and parts are described in new leaflet by Despatch Oven Co. Bulletin 362.

New booklet describes uniform case hardening up to .150" with controlled carburizing baths. American Cyanamid & Chemical Corp. Bulletin 372.

New book "Hardness" describes and evaluates hardness research of noted pioneers, methods of testing and testing instruments. Nitralloy Corp. Bulletin 366.

Rapid oil coolers and heat transfer equipment are described in new catalog issued by Bell & Gossett Co. Bulletin 365.

Four basic heat treating atmospheres are described in new booklet by Westinghouse. Bulletin 383.

Laboratory and tool room furnace. Mahr Mfg. Co. in new Bulletin 327.

"Heat Treating Topics" is title of new bulletin of special interest to heat treaters, issued by Rex & Erb. Bulletin 424.

Vapocarb-Hump method for heat treatment of steel is the title of a newly-revised catalog issued by Leeds & Northrup. Bulletin 453.

The complete line of heat treating furnaces, burners and other equipment of this company is described and illustrated in new bulletin "D" just issued. Eclipse Fuel Engineering Co. Bulletin 483.

Thirty-two-page booklet, "Production Data," presents several articles from "The Houghton Line." E. F. Houghton & Co. Bulletin 475.

112 pages packed solid with down-to-earth data on industrial combustion and heat practice. Hauck Mfg. Co. Bulletin 477.

A new technical bulletin gives information on Calliflex Bi-metal. Callite Tungsten Corp. Bulletin 478.

Several types of Surface Combustion production forge furnaces are described in this new bulletin 496.

Interesting 20-page booklet contains extensive heat treating information, including a glossary of terms, table of weights of square and round bars and a hardness conversion table. Pittsburgh Commercial Heat Treating Co. Bulletin 509.

REFRACTORIES & INSULATION

Insulating firebrick. Babcock & Wilcox Co. Bulletin 162.

Heavy Duty Refractories. Norton Co. Bulletin 164.

Cromox, new protective refractory coating material for prolonging life of firebrick, insulating firebrick, and castable refractories. Federal Refractories Corp. Bulletin 163.

Conductivity and heat transfer charts. Johns-Manville. Bulletin 167.

D-E insulating materials and their application are described in new data booklet by Armstrong Cork Co. Bulletin 208.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature.

Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1178, 1180, 1182, 1184, 1186, 1188, 1192, 1194, 1196 and 1198.

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

Zircon refractories in aluminum open hearth furnaces. Chas. Taylor Sons Co. Bulletin 347.

"Gunmix", a new series of refractories designed for rapid emplacement by air stream and water, is described and illustrated. Basic Refractories, Inc. Bulletin 480.

Steel Plant Cement for hot or cold patching of soaking pits, open hearths, electric furnaces, forging furnaces and reheating furnaces is described in new folder by Electro Refractories & Alloys Corp. Bulletin 407.

"Carbofrax" refractory skid rails are described and blueprinted for many types of furnaces in this 20-page booklet by the Carborundum Co. Bulletin 500.

FINISHING • PLATING • CLEANING

Roto-Finish equipment for deburring, buffing, polishing and coloring. Sturgis Products Co. Bulletin 170.

A protective, deep black finish to steel. Heatbath Corp. Bulletin 171.

Alvey Ferguson Co. shows how various product washing problems were solved. Bulletin 172.

Motor-Generators for electroplating and other electrolytic processes. Columbia Electric Mfg. Co. Bulletin 173.

Pickling. Wm. M. Parkin Co. Bulletin 174.

Detrex metal cleaning machines, metal cleaning chemicals and processing equipment. Detrex Corporation. Bulletin 175.

Electrochemical Descaling. Bullard-Dunn Process Div., Bullard Co. Bulletin 212.

Airless Rotoblast. Pangborn Corp. Bulletin 176.

Rust inhibiting wax coatings for protection of metal. S. C. Johnson & Son, Inc. Bulletin 180.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature.
Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1178, 1180, 1182, 1184, 1186, 1188, 1190, 1194, 1196 and 1198.

WHAT'S NEW

IN MANUFACTURERS' LITERATU

Cadmium Plating. E. I. duPo deNemours & Co., Inc. Bulletin 17

Tumbling and cleaning. Glo Stamping and Machine Co. Bullet 179.

Catalog on finishing and cleanin Frederick Gumm Chemical Co., In Bulletin 292.

Resilon corrosion-resistant tan linings and applications are d scribed in 8-page leaflet by Unit States Stoneware Co. Bulletin 291.

"Indium and Indium Plating". I dium Corp. of America. Bulletin 18

Jetal process and its characteri tics as a protective coating. Alro Chemical Co. Bulletin 213.

Illustrated booklet describes bla cleaning equipment offered b Ruemelin Mfg. Co. Bulletin 360.

Lead plating is discussed in ne booklet issued by Harshaw Chemic Co. Bulletin 109.

Service report describes use Oakite machining, drawing, degrea ing and descaling materials. Oaki Products, Inc. Bulletin 210.

Three new booklets have been i sued by the Enthone Co. describin an acid addition agent, hard dryi rust-inhibiting waxes and a new kali steel cleaner. Bulletin 420.

Special data sheets on compoun for various cleaning jobs are offer by MacDermid, Inc. Bulletin 436.

Technical bulletin describes m terials developed to meet speci ized processing and cleaning need Kelite Products, Inc. Bulletin 438.

New 1944 catalog describes met cleaning equipment offered by Ransohoff, Inc. Bulletin 439.

Several practical data sheets sho cleaning methods used on aluminu brass and steel. Diversey Corp Bulletin 446.

New 144-page catalog "Chemical by Glyco" features many tables useful chemical and physical dat Glyco Products Co., Inc. Bulleti 449.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature. Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1178, 1180, 118 1184, 1186, 1188, 1190, 1192, 1196 and 119

WHAT'S NEW

IN MANUFACTURERS' LITERATURE

Cyanide zinc and bright zinc plating with Turco Type X, Turco Porokleen and Turco Penetrol is described in this 10-page booklet by Turco Products, Inc. Bulletin 495.

American Chemical Paint Co. has issued an illustrated technical service data folder on Rodine, a standard control for the pickling bath. Bulletin 505.

ENGINEERING • APPLICATIONS • PARTS

Carburizing Boxes. Pressed Steel Co. Bulletin 193.

Chace manganese alloy No. 772 in sheets, strips, rod and special shapes described by W. M. Chace Co. Bulletin 190.

Pressed steel pots are described by Bell & Gossett Co. in new Bulletin 364.

Catalog gives complete specification data on Bunting bearings and bars. Bunting Brass & Bronze Co. Bulletin 343.

New 32-page illustrated booklet contains much data on manganese steel for the railroad industry. American Manganese Steel Div. Bulletin 388.

Illustrated leaflet presents data and uses of special alloys resisting corrosion, high temperatures and abrasion. The Duraloy Co. Bulletin 390.

Heat treating fixtures for pit-type furnaces are shown in new booklet by Driver-Harris Co. Bulletin 363.

New information sheets on tapered and formed tubes have just been issued by Summerill Tubing Co. Bulletin 369.

54-page booklet, "File 41 — Engineering Data Sheets", gives complete facts on Ampco Metal's physical properties and service record. Bulletin 368.

Electrical, corrosion and heat resisting alloys in rod, wire, ribbon and strip forms. Wilbur B. Driver Co. Bulletin 192.

X-Ray Inspected Castings. Electr Alloys Co. Bulletin 197.

Steel Castings. Chicago Steel Fou dry Co. Bulletin 199.

Heat Resisting Alloys. General A loys Co. Bulletin 200.

Pipes and Tubes. Michigan Ste Casting Co. Bulletin 201.

Bimetals and Electrical Contact H. A. Wilson Company. Bulletin 20

Cr-Ni-Mo Steels. A Finkl & So Co. Bulletin 203.

Industrial baskets, crates, trays an fixtures. Rolock, Inc. Bulletin 20

Cooper standard alloys. Coope Alloy Foundry Co. Bulletin 206.

Many applications and savin through use of drop forgings a shown in Drop Forging Topic issued by Drop Forging Assn. Bu letin 240.

24-page catalog is guide to prope ties and use of Monsanto plastic Monsanto Chemical Co. Bulletin 31

Details of new Chemicast proce for small brass parts will be supplie by Chemicast Div., Whip-Mix Cor Bulletin 330.

Reference data book entitled "Th Improvement of Metals by Forgin has been issued by Steel Improv ment & Forge Co. Bulletin 409.

Illustrated leaflet describes stai less steel castings by Atlas Foundr Co. Bulletin 437.

Industrial applications of Natio al and Karbate carbon and graphi products are illustrated in 16-pa booklet issued by National Carbo Co., Inc. Bulletin 426.

Many types of heat treating an pickling baskets and containers a shown in new booklet by the Sta wood Corp. Bulletin 445.

Complete line of Mallory radi electrical and electronic parts, wi sizes, dimensions and rated capa ities is described in new 36-pa booklet. P. R. Mallory & Co., In Bulletin 448.

Interesting and informative liter ture on "Pomet" powder metallur products. Powder Metallurgy Cor Bulletin 454.

Specifications and physical pro erties of bronze and aluminum allo are shown in Olds Alloys Co. Bulle tin 457.

Aluminum and aluminum allo screws, bolts, nuts, rivets an washers are detailed in this 60-pa catalog. Aluminum Co. of Americ Bulletin 485.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature. Other Manufacturers' Literature Listed on Pages 1172, 1174, 1176, 1178, 1180, 118 1184, 1186, 1188, 1190, 1192, 1194 and 119

WHAT'S NEW
IN MANUFACTURERS' LITERATURE

Handsome 12-page brochure pictures the cast steel breech rings and their advantages as produced by the Ohio Steel Foundry Co. Bulletin 515.

Illustrating several heat resistant alloy applications, this 4-page leaflet cites four factors essential to efficient alloy use. Sterling Alloys, Inc. Bulletin 504.

Three-color chart of decimal equivalents. John Hassall, Inc. Bulletin 458.

"Mechanical Springs, Their Engineering and Design" is the title of a 106-page handbook just issued jointly by the divisions of Associated Spring Corporation. Bulletin 481.

MELTING • CASTING • MI OPERATIONS

Ingot Production. Gathmann En neering Co. Bulletin 185.

8-page illustrated booklet descri crucible melting furnaces for br bronze, aluminum, copper and ot alloys. Stroman Furnace & En neering Co. Bulletin 473.

Crucibles for brass, copper, alu num and magnesium industri Electro Refractories and Alloys Co Bulletin 183.

This ring-binder presents 24 pa on the use and effect of Titanium steel and cast irons. Titanium Al Mfg. Co. Bulletin 470.

52-page booklet describes Mo rapid Lectromelt furnaces for ir steel, nickel and copper melting a refining. Pittsburgh Lectromelt F nace Corp. Bulletin 404.

"Electromet Products and Servic Electro Metallurgical Co. Bulle 186.

Interesting and helpful infor tion available on the use of al pots for heating operation by Swedish Crucible Steel Co. Bulle 137.

Electric Furnaces. Detroit Elec Furnace Div., Kuhlman Electric Bulletin 189.

Operating Features, capaciti charging methods of the Her electric furnace. American Bri Co. Bulletin 215.

"Fisher Magnesium Scrapbo Fisher Furnace Co. Bulletin 28

Attractive booklet descr growth, facilities and offers valu alloy hints. Niagara Falls Sme & Refining Corp. Bulletin 246.

Interesting, descriptive leafle metal reclaiming mill offered Dreisbach Engineering Corp. B tin 284.

Foundry ovens for core bak mold drying and pasting are i trated in new 4-page leaflet Despatch Oven Co. Bulletin 51

GENERAL

New leaflet describes intero communication system offered Executone Communication Syste Bulletin 385.

"Aluminum Progress" is title new publication to be issued re larly presenting a bird's-eye view the latest news of this metal. R nolds Metals Co. Bulletin 498.

Use Handy Coupon on Page 1172 for Ordering Helpful Literature. Other Manufacturers' Literature Lis on Pages 1172, 1174, 1176, 1178, 1180, 1 1184, 1186, 1188, 1190, 1192, 1194 and 1